An investigation into HVAC option for an office building in Pakistan

by

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Abstract

This report determines various means of achieving energy efficient HVAC systems for a built environment within an industrial establishment. A technical feasibility is carried out to check if enough waste heat recovery is available to feed plant side of a proposed HVAC system at the unit. It also looks into energy efficient means of providing comfortable environmental solution for the building.

To investigate these criteria an industrial establishment is selected which is situated in Islamabad, Pakistan. The user requirements are analysed and solution is suggested to meet the requirements.

To carry this out waste heat sources are determined and calculations are carried out to attempt sizing the plant side of the HVAC system with the available heat source. Further energy simulations are carried out to determine most energy efficient ventilation system for the external conditions of Islamabad Pakistan.

Results from the energy simulations shed light on the performance of the various ventilation systems considered along with the building fabric of the structure of the industrial unit.

In conclusion appropriate ventilation system is recommended with improvements to the building fabric to achieve efficient and least energy intensive building services for the industrial unit.

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1.0 Background on Pakistan

Pakistan is located in the Southern Asian continent, bordering the Arabian Sea, between India on the east, Iran and Afghanistan on the west and China to the north. Geographic co-ordinates of Pakistan are 30° N and 70° E.

1.1 Energy problems in Pakistan

The energy crisis of the early 1970's saw dramatic change in planning of the development in the country. Emphasis was given to the optimal utilisation of the energy resources as the fact remained that the requirement of the primary fuel was met through imports of crude oil from the middle-east countries.

In recent years Pakistan has witnessed a growing trend of power shortages or power cuts along with the ever increasing energy costs. This has not only affected the standards of living but also hindered the industrial development in the country. The demand for electricity is primarily met by hydro electric dams and thermal generation plants. There are numerous factors because of which the supply of energy can not keep up with demand. This is primarily due to slower rate of increase of generation capacity, decreasing capacity of existing dams, leading to fall in hydro-electricity, increasing cost of fuel required for thermal generation plants, rapid urbanisation due to increased construction activity. All these factors and numerous others have widened the gap between supply and demand of the energy.

1.2 Primary energy consumption

More than 85% of energy in Pakistan is produced through the use of fossil fuels, primarily natural gas and petroleum. The remaining 15% consists of renewable or other energy sources such as hydro-power, biomass and nuclear energy. Emissions by energy source in Pakistan are estimated as below:

Oil	39.2%
Gas	38.0%
Coal	7.7%
Renewable/Other	15.1%
Total	100%

Table 1.1: Break down of primary sources

Source: The National Energy Conservation Centre Ministry Of Environment, LG&RD Government Of Pakistan

A break down of primary source of energy supplied to generate electricity can be seen from the chart below.

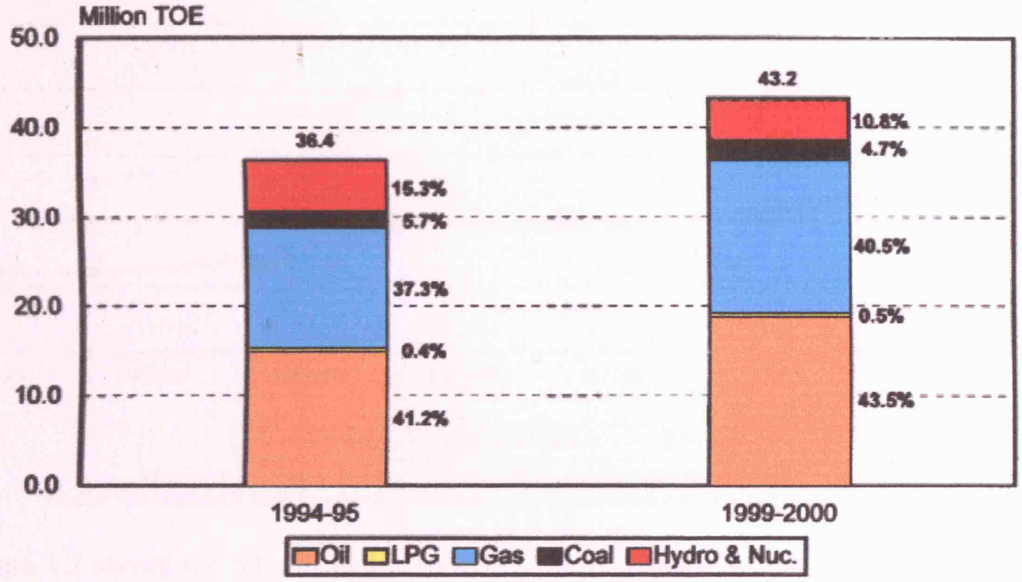


Figure 1.1: Break down of primary energy sources

Source: The National Energy Conservation Centre Ministry Of Environment, LG&RD Government Of Pakistan

From the figure above a decreasing trend can be seen for the reliance in utilisation of hydro-power, nuclear power and renewable sources where as an increase in the consumption of fossil fuel can be seen for the period of five years from 1994 to 2000.

1.3 Consumption of Petroleum products

According to the energy book 2000 published by the PEEMAC (Pakistan Energy and Environment Management Centre), trend in increase of fuel prices are given in the 'Figure 1.2'.

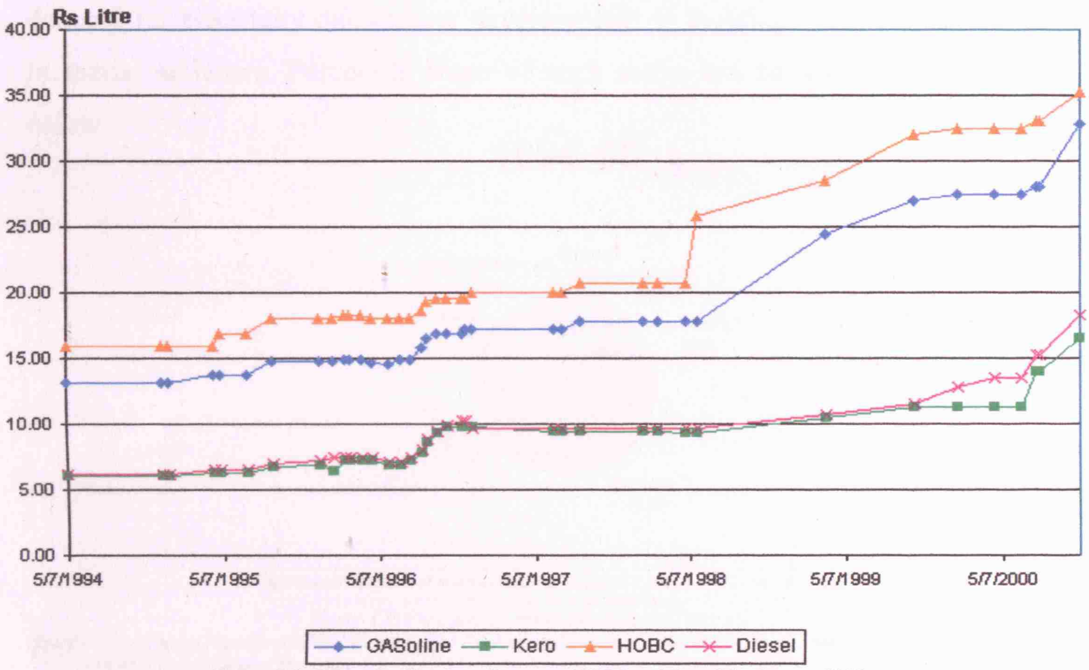


Figure 1.2: Prices for Gasoline, Kerosene, HOBC and Diesel for the year2000
Source: The National Energy Conservation Centre Ministry of Environment, LG&RD Government of Pakistan

Figure 1.2 shows the hike in motor spirits, kerosene and diesel oil. Since 2000 average percentage increase in price of diesel has been recorded at 70%. Most of the power generation plants in Pakistan depend on the cheap availability of diesel oil. With the increase in the fuel prices cost of electricity price has increased and is still rising due to the current international market circumstances.

Petroleum energy consumption by sectors (TOE)

Sectors	1994-95	1999-2000
Domestic	585,173.00	447,305.00
Industrial	1,889,443.00	2,115,860.00
Agriculture	268,631.00	293,034.00
Transport	6,646,175.00	8,307,977.00
Power	4,215,635.00	6,227,595.00
Other Gov.	355,110.00	346,050.00
Total	**13,960,167.00**	**17,767,821.00**

Table 1.2: Petroleum energy consumption by sector
Source: The National Energy Conservation Centre Ministry of Environment, LG&RD Government of Pakistan

The quantities of petroleum product ('TOE' Tonne oil equivalent) as a source of energy used by different sectors can be seen from the 'Table' above. Over the period from 1994-2000 it can be seen that consumption of petroleum products have increased for Power generation and industrial sector. This increase in the power generation sector reflects the demand for electricity due to new developments in building construction and increased industrial activities. Percentile share of each sector can be seen from the chart given below.

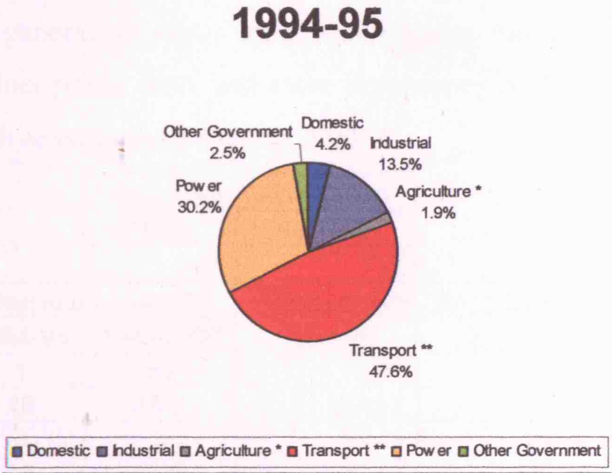


Figure 1.3: Pie chart of percentile share for 1994-95

Source: 'The Energy Handbook 2000' Published by the National Energy Conservation Centre Ministry of Environment, LG&RD Government of Pakistan

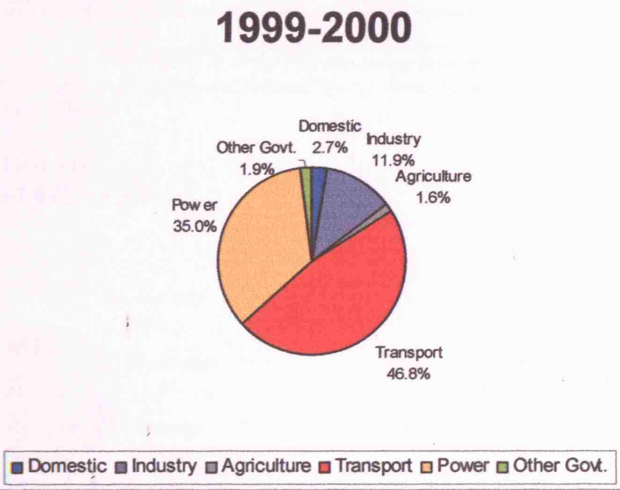


Figure 1.4: Pie chart of percentile share for 1999-2000

Source: 'The Energy Handbook 2000' Published by the National Energy Conservation Centre Ministry of Environment, LG&RD Government of Pakistan

In view of these circumstances many industries and the construction industry, in order to reduce their in-house energy requirements need to consider saving through energy efficient systems and better building designs respectively.

1.4 Consumption of Natural gas

Apart from petroleum products another source of primary energy available in Pakistan is Natural Gas. Pakistan is self sufficient in its production. The major portion is consumed by the electricity generation plants after which comes the domestic sector. With the increase in fossil fuel prices more and more dependency on Natural Gas has been seen over the period of five years from 1994 to 2000.

		Production, Billion Cu.Ft.			
Total Production		1994-95	1999-2000		
		547	715		
Sectors	Percentile share %		Consumption, Billion Cu.Ft.		Percentage increase
	1994-95	1999-2000	1994-95	1999-2000	
Cement	1	1.2	5.47	8.58	56.86%
Gen. Industry	19	18.9	103.93	135.14	30.03%
Commercial	3	3	16.41	21.45	30.71%
Domestic	18	19.6	98.46	140.14	42.33%
Transport	0	0.3	0.00	2.15	-
Power	33	32.2	180.51	230.23	27.54%
Fertilizer	26	24.8	142.22	177.32	24.68%
		Total	547	715	

Table1.3: From Pakistan energy book 2000

Source: 'The Energy Handbook 2000' Published by the National Energy Conservation Centre Ministry of Environment, LG&RD Government of Pakistan

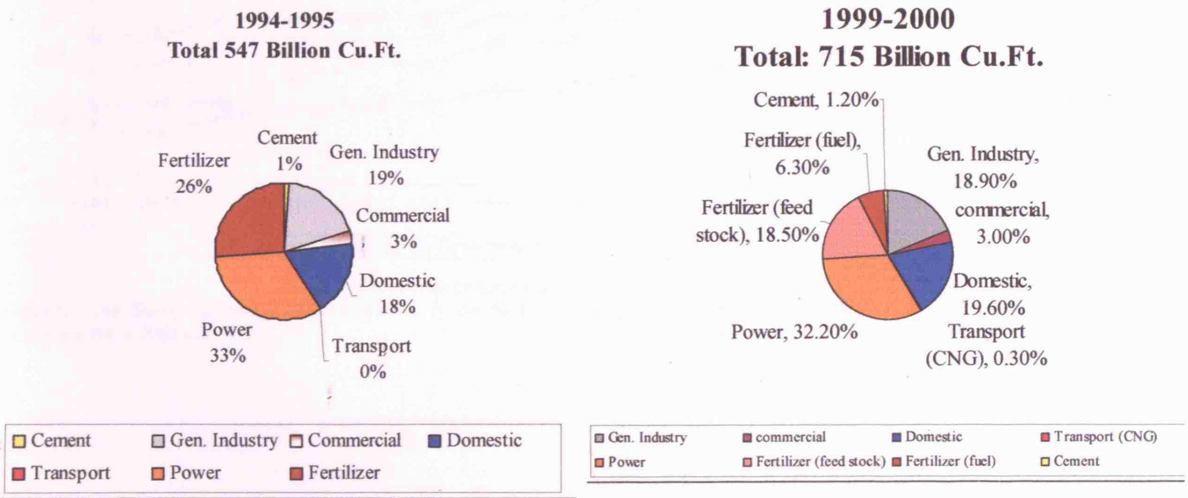


Figure1.5: Natural gas consumption by sector for the year of 1994-1995 and 1999-2000

Source: 'The Energy Handbook 2000' Published by the National Energy Conservation Centre Ministry of Environment, From the charts it can be seen that with the increase in the production of Natural gas is matched with consumption from new sectors, as it is a cheap alternative fuel. From the table above it can be seen that since 1994-95 increase in natural gas consumption for power generation has increased by 27% approximately. With the increase in the demand, the cost of gas per cubic foot has also increased and can be seen from the figure below. This increase in fuel prices are also caused by the unstable International market. Since Pakistan is a developing country, with ever increasing demand for energy and the fact that the economic growth of a country depends on the industrial growth, which require cheaper alternatives of energy resources. One way of achieving this is to look into the areas of efficient utilisation of the available resources. The trend of increase in the price of natural gas for different sectors for the period of 1994-2000 is given in the graph above.

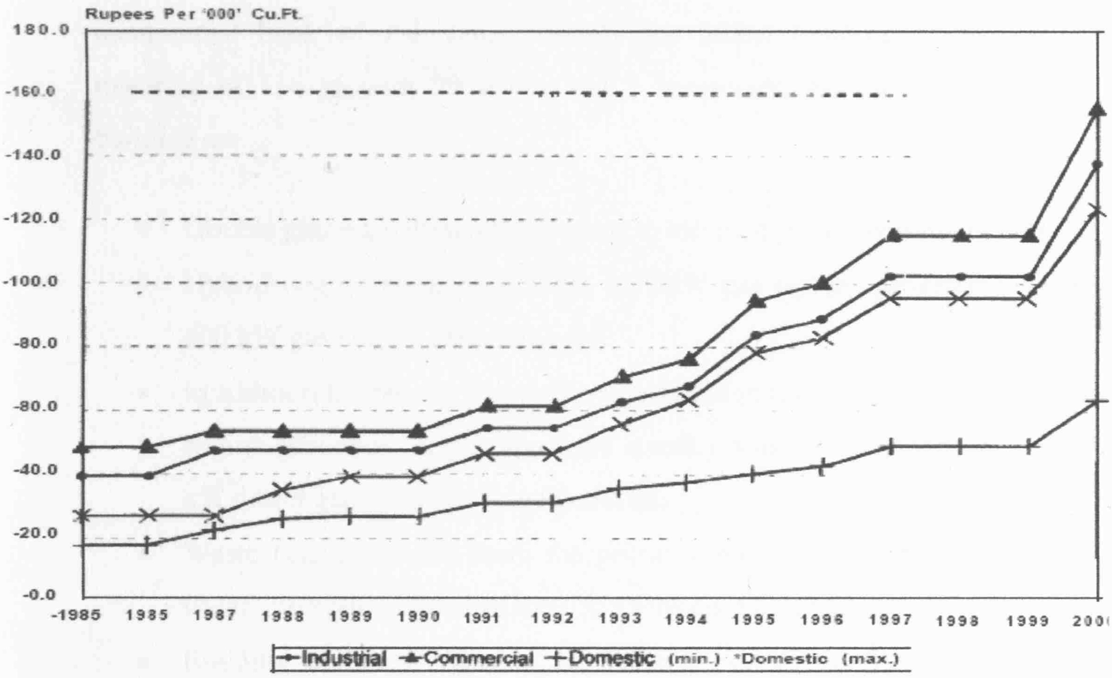


Table 1.4: Increase in natural gas prices from 1985 to 2000
Source: 'The Energy handbook 2000' Published by the National Energy Conservation Centre, Ministry Of Environment, LG&RD Government of Pakistan

1.5 Adaptation, due to higher cost of energy

With the ever increasing demand and cost of energy, some of the factors discussed above, consumers for different sectors have initiated alternate means to meet their demands. One of the approaches taken by the industrial sector as well as by commercial building is to employ cogeneration units. Cogeneration or combined heat and power systems not only supply reliable source of electricity but they are also capable of supplying heating or cooling for the premises. By adopting such solutions, these sectors have not only secured their energy requirements and environmental comfort need but they have also increased their plant efficiencies. Subsequently they have reduces their energy costs.

1.5.1 An example of a commercial building

MCB (Muslim commercial bank) tower is a new acquisition of Muslim commercial bank of Pakistan, currently the tallest building in the country towering at 116 m with 29 levels and 3 basements. Salient features of this building are

- Double glazing with tempered glass to increase its strength by 5 times.
- Hybrid cogeneration plant, with 1.2 MW gas turbine generating set and 600 kW gas engine generating set.
- In addition to above prime movers, installation also includes a 300 kW gas engine generator for part load and standby operation in addition to a 300 kW diesel generator for standby duties.
- Waste heat recovered from the prime movers is utilised to operate hot water absorption chiller of total 550 tons cooling capacity.
- Building employs Variable air volume (VAV) ventilation system for supplying cooling to the different parts of the building.

1.5.2 An example of an industrial sector

International industries (LTD) one of the biggest galvanised pipe and fixture manufacturers have recently opted to switch from national grid to generate indigenous electricity. Floor workshop of this industry mainly consists of a furnace for melting iron, extrusion plants to produce galvanised pipe and casting facility for galvanised fixtures. Their initial requirements were.

- To provide energy demands for their workshop floor
- Meet the cooling loads of the administrative building.
- Meet the cooling load of the extrusion plant. In extrusion process cooling is required to keep the temperatures of the extrusion moulds so as to increase their productive life.

Salient features of the cogeneration plant are.

- 3 MW gas turbine engine.
- Waste heat extracted to produce 2-3 tonne of steam.
- Total capacity of an absorption chiller 225 tonne (Double effect absorption chiller).

SETTING THE THERMAL COMFORT CRITERIA FOR THE INDOOR ENVIRONMENT

2.0 Thermal comfort

ISO 7730 standard, defines thermal comfort as:

"That conditions of mind which expresses satisfaction with the thermal environment"

The range of environmental temperature at which the occupant of that environment feels neither hot nor cold, in other words being at thermal neutrality can be referred to as 'comfort zone'. This can be achieved when there is a balance between metabolic heat production and heat loss. Thermal comfort of an environment depends on following factor.

- i) Environmental condition
  - a) Air temperature or dry bulb temperature (°C)
  - b) Humidity (Relative humidity RH %)
  - c) Air movement (speed 'v' m/s)
  - d) Radiation (Mean radiant temperature MRT)
- ii) Metabolic rate or activity (MET).
- iii) Clothing insulation (clo.).

2.0.1 Environmental Condition

In door environmental conditions of a building has following factor to be considered.

a) Air temperature:

Air temperature is often taken as the main design parameter for thermal comfort. Air temperature or the dry bulb temperature is the air temperature around the occupant. Out of the entire environmental factor, body is most sensitive to the variation in temperature affecting the comfort criteria. It is that temperature that the designer tries to keep with in the range of comfort zone. The CIBSE recommendation for internal temperature is between 19 °C to 23 °C during winter and less than 27 °C during summer, with the temperature gradient between head and feet should not be less than 4 C. For air-conditioned and heated building it is usual to specify an acceptable temperature control zone width. Auliciems (1983) suggested a zone of plus or minus 2 degree °C.

b) Relative Humidity (RH %)

The effect of evaporative cooling depends on the relative humidity of the space. Relative humidity is the measure of the amount of vapour in the air at a given temperature to the total amount of vapour air can hold at that temperature. Relative humidity has little effect on evaporation when the air temperature is with in the comfort zone.

c) Air movement (speed 'v' m/s)

The effect of air movement on the comfort environment depends on following two factors;

a) Air temperature.

b) Relative humidity.

Air movement help improve convective heat loss from the body, correct air movement can increase convective heat loss if the temperature of the air is less than the temperature of the skin. Air speed has little effect when the relative humidity levels are less than 30% at which there is an unrestricted evaporation even in still air whereas at humidity levels at and above 85% air movement has little effect as the air is already saturated.

2.0.2 Radiation (Mean radiant temperature MRT)

The mean radiant temperature is the area weighted average of all the surface temperatures of the room. If the surfaces are at different temperatures the affect of the radiant temperature on the person will be due to the position in relation to different surfaces. Radiant asymmetry can affect the thermal comfort of the habitat. Different combinations of mean radiant temperature with dry bulb temperature that will give thermal sensation of 21.11 C are given below.

MRT C	18.33	18.88	19.44	20	20.55	21.11	21.66
DBT C	25	24.22	23.44	22.66	21.88	21.11	20.33

Table 2.1: Combinations of dry bulb and mean radiant temperatures

2.0.3 Metabolic rate or Activity (MET)

Human body generates heat through metabolic process. The term metabolism describes the biological process with in the body that lead to the production of heat. Body has to maintain the core temperature of 37°C whereas the sensors on the skin are most sensitive at 34°C. The heat generated by the body is measured in MET.

$$1 \text{ MET} = 58 \text{ W/m}^2$$

This value of MET is taken over the body surface area. Average body surface area of an adult is 1.8 m^2. Table below give some typical MET values for different activities.

Activity	*Metabolic rate* (met)
Sleeping	0.7
Sitting	1.0
Standing	1.2
Typical office work	1.2
Walking (1.3 m/s)	1.6
Heavy machine work	3.0

Table 2.2: Typical MET values for different activities

2.0.4 Clothing or insulation (clo.)

One way of regulating the rate of heat loss from the body is by clothing. The insulation of clothing is measured in units of clo. 1 clo is equal to 0.155 m^2 K/W the unit are those of internal resistance. Clo Values of typical clothing are given below in the table.

	CLO	(m^2K/W)
Nude	0	0
Light summer clothes	0.5	0.08
Light working ensemble	0.7	0.11
Winter indoor	1.0	0.16
Heavy business suit	1.5	0.23

Table 2.3: Typical Clo. Values for different clothing

2.1 Psychometric chart

The design of a habitat which reflects the analysis of environmental variable such as dry bulb temperature, humidity, air movement and radiant temperature can be called Bio-climatic design. This analysis can be carried out either with the help of bio-climatic charts or psychometric charts. Psychometric charts were developed for engineering calculation of HVAC systems. Psychometric charts helps in determining the comfort zone by looking into the environmental factors for a person engaged in specific activity wearing specific amount of clothing insulation.

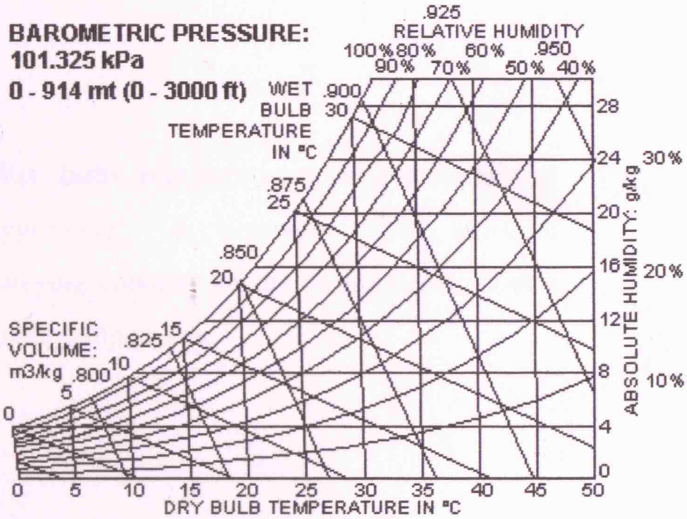
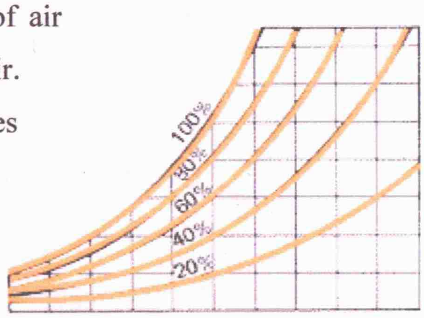


Figure 2.1: Psychometric chart

Psychometric charts represents the state of a given environment by point which gives dry bulb temperature, wet bulb temperature, relative humidity, specific volume and saturation temperature of the atmosphere.

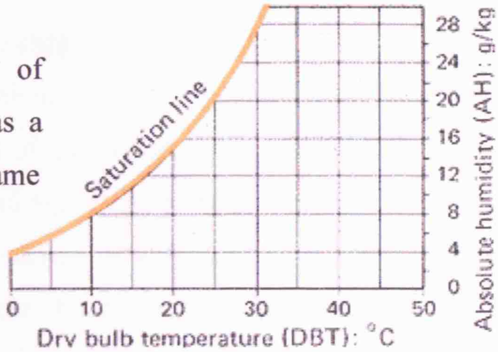
Different components of psychometric charts are given below.

a) **Absolute humidity;** is the vapour content of air given in grams of water per kilogram of air. This quantity can be read from the right sides indices of the chart.

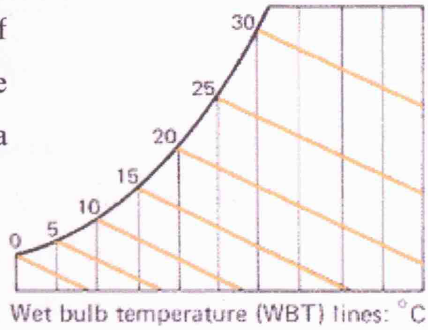


Relative humidity lines (RH): %

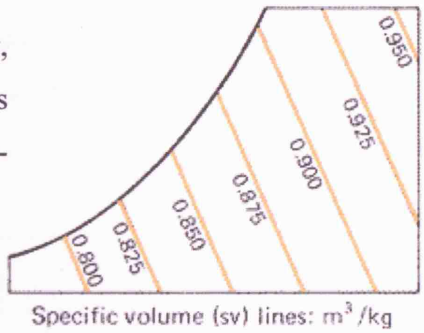
b) **Relative humidity;** is an expression of moisture content of a given atmosphere as a percentage of saturation humidity at the same temperature.



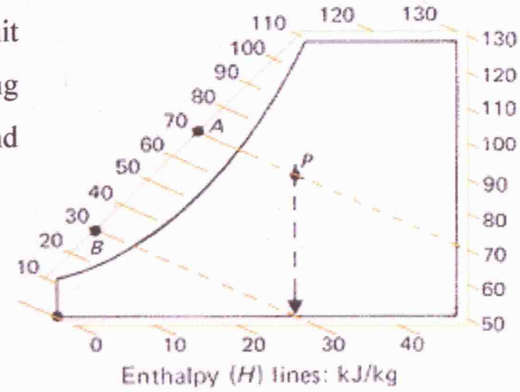
c) **Wet bulb temperature;** is a measure of hygrometer, it represents the moisture carrying capacity of the atmospheric air at a given temperature.



d) **Specific volume;** is the reciprocal of density, useful in conversion of volumetric flow rates quantities into mass flow rate for air-conditioning calculations.



e) **Enthalpy;** is the heat content of the unit mass of the atmosphere. It is used in making air-conditioning assessments and calculations.



2.2 Temperature standards for thermal comfort in Pakistan

Pakistan's limited energy resources demands promotion of energy conservation and efficient use of energy. In 1984 under the advisement of the World Bank and with the help of USAID, Pakistan government formed a national agency to achieve the objective of efficient energy use and energy conservation named ENERCON. ENERCON produced Building Energy Codes for Pakistan, where the recommended indoor air temperature for the buildings were set at 26°C for cooling season and 21°C for heating season, irrespective of the fact where the building is located in Pakistan. These standards were based on ASHAE standards.

In buildings, a major fraction of energy is used by air-conditioning systems, where the cost of air-conditioning is affected by the indoor temperatures. Realising this ENERCON commissioned a team to under take series of longitudinal and transverse survey in order to advise on setting of appropriate indoor temperature for different regions of Pakistan. The aim of these surveys was to determine appropriate indoor temperature for different zones of Pakistan. On the basis of homogeneity of climatic elements such as temperature and precipitation, the country was divided into five climatic zones and one city from each zone was chosen.

Climatic zone		Representative city	Temperature range (°C)
Zone I	Tropical coastland	Karachi	18.1-31.4
Zone II:	Subtropical continental - lowlands arid	Multan	12.8-35.5
Zone III:	Subtropical continental - highlands semi-arid/ sub-humid	Quetta	4.9-27.8
Zone IV:	Subtropical continental - lowlands sub-humid	Islamabad Peshawar	10.1-31.2
Zone V:	Subtropical continental - highlands humid	Saidu Sharif	8.2-28.7

Table 2.4: Climatic zones of Pakistan

Source: 'Thermal comfort in Pakistan' School of Architecture, Oxford Brookes University, Oxford, UK

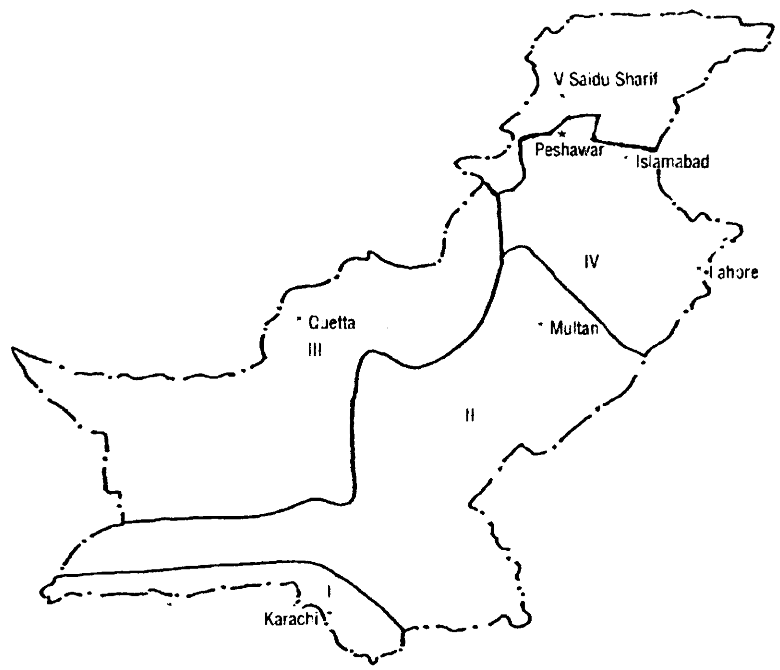


Figure 2.2: Climatic zones of Pakistan
Source: 'Thermal comfort in Pakistan' School of Architecture, Oxford Brookes University, Oxford, UK

The first survey was longitudinal, conducted in 1993-94 in five cities of Pakistan with 25 subjects for a week in two seasons. The results of this survey were inconclusive as there were big variations in thermal comfort temperatures of different climatic zones. Following doubts, during 1995-96 a second survey transverse was conducted using 846 subjects at monthly intervals over a whole year.

Results from these survey showed that in-door thermal comfort temperature could be predicted from out door temperatures which varies for each month in different climatic zones. For buildings with heating and air-conditioning recommended in-door temperature are guided by following relationship;

$$T_c = 17.0 + 0.38\ T_o$$

T_c = Comfort temperature

T_o = Mean out-door temperature.

Comfort temperature based on this relation resulted in 20% energy saving as compared to ASHRAE standard temperature. The range for comfort temperature as suggested by the survey for Islamabad (located in zone IV of the climatic zones of Pakistan) is given below.

$T_c = 20.9$ in winter season.

$T_c = 28.4$ in summer season.

Psychometric chart below represents the thermal comfort zone based on these findings.

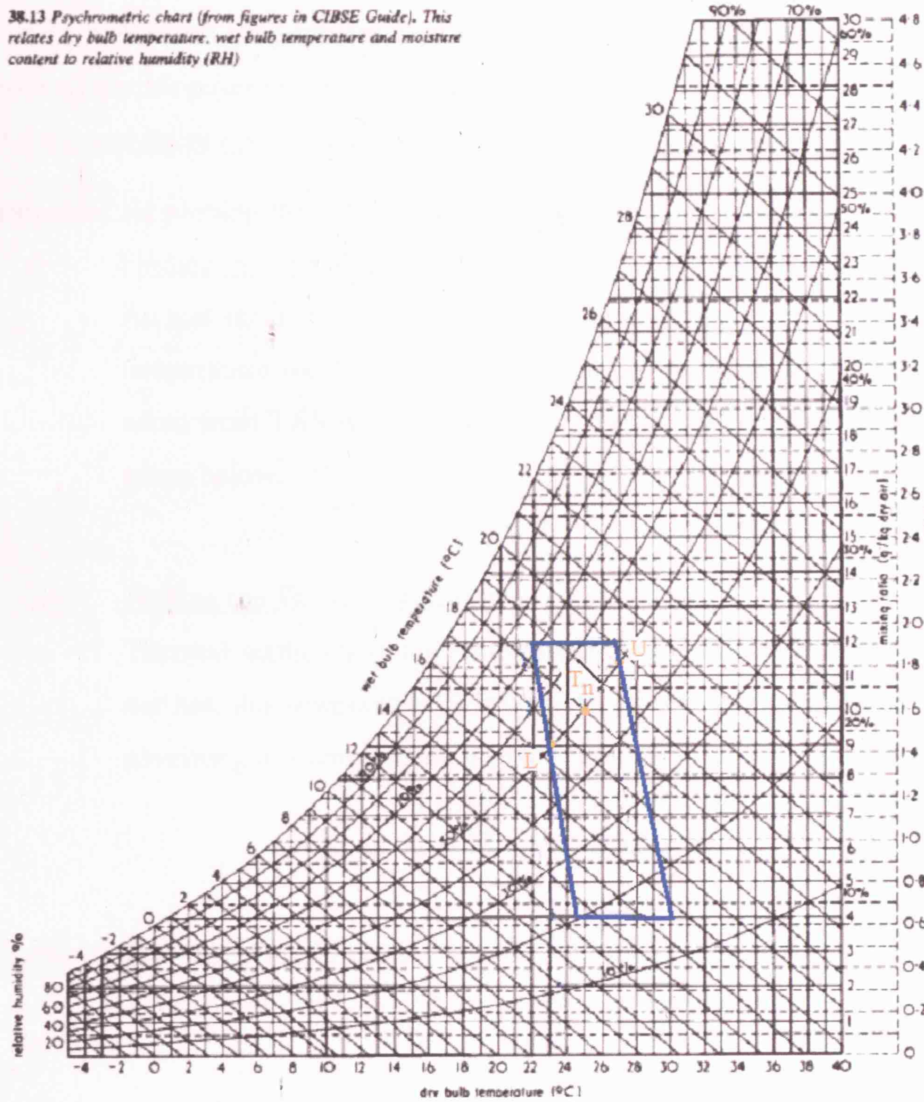


Figure 2.3: Comfort zone with correlation from the survey

2.3 Predicting the thermal comfort zone for the building in Islamabad

In-order to determine the comfort temperature for a building in Islamabad a thermal comfort zone was plotted on a psychometric chart. This exercise was under taken by following a web based program for plotting comfort zone on a psychometric chart. The web address for this psychometric tool is given below.

http:// www.architecture.arizona.edu/architecture/academic/graduate/peyush/anal.html

The procedure for plotting the comfort zone is as follows.

i) Finding the annual mean temperature

Annual mean temperature is taken by averaging the outdoor dry bulb temperature for the whole year. Dry bulb temperature for Islamabad was taken from TAS weather file. Mean average temperature for Islamabad is given below.

$$T_{av} = 21.385\ ^{o}C$$

ii) Finding the Thermal neutrality

Thermal neutrality is the temperature at which subject feels neither cold nor hot, this temperature is influenced by out-door temperature. Equation governing this temperature is given below.

$$T_n = 17.6 + 0.31\ T_{av}$$
$$T_n = 17.6 + 0.31\ (21.385)$$
$$T_n = 24.23\ ^{o}C$$

iii) Finding Upper (U) and Lower (L) limit of T_n (Thermal neutrality)

These limits can be found from following equations

$L = T_n - 2$	$U = T_n + 2$
$L = 24.23 - 2$	$U = 24.23 + 2$
$L = 22.23\ ^{o}C$	$U = 26.23\ ^{o}C$

v) Finding the SET (Standard effective temperature) slope expression

The standard effective temperature (SET) are thermal indices express in a single number the combined thermal effect of environmental variables such as DBT (Dry bulb temperature) and humidity, when the MRT (Mean radiant temperature) is the same as the DBT and there is no significant air movement. The SET lines are given as follows.

Up to 14°C SET lines coincide with the DBT (vertical) lines whereas above 14°C, the SET coincides with DBT at the 50% RH curve, but the lines have a slope of 0.025 x (DBT - 14) for each g/kg (AH) vertical distance.

Lower limit = L = 0.025 x (22.23 – 14) = 0.205 °C/ (g/Kg)

Upper limit = U = 0.025 x (26.23 – 14) = 0.305 °C/ (g/Kg)

v) Finding base line intercept for L and U from SET slope expression

Base line intercept for L = L + [AH (L) x 0.205)]

Where

AH (L) = Absolute humidity taken from the psychometric chart

= 8.5 g/Kg

Therefore

Base line intercept for L = 22.23 + [8.5 x 0.205] = 23.97 °C

Base line intercept for U = U + [AH (U) x 0.305)]

Where

AH (U) = Absolute humidity taken from the psychometric chart

= 10.7 g/Kg

Therefore

Base line intercept for U = 26.23 + [10.7 x 0.305] = 29.5 °C

Thermal comfort zone from these variables is shown on the psychometric chart given below.

38.13 *Psychrometric chart (from figures in CIBSE Guide). This relates dry bulb temperature, wet bulb temperature and moisture content to relative humidity (RH)*

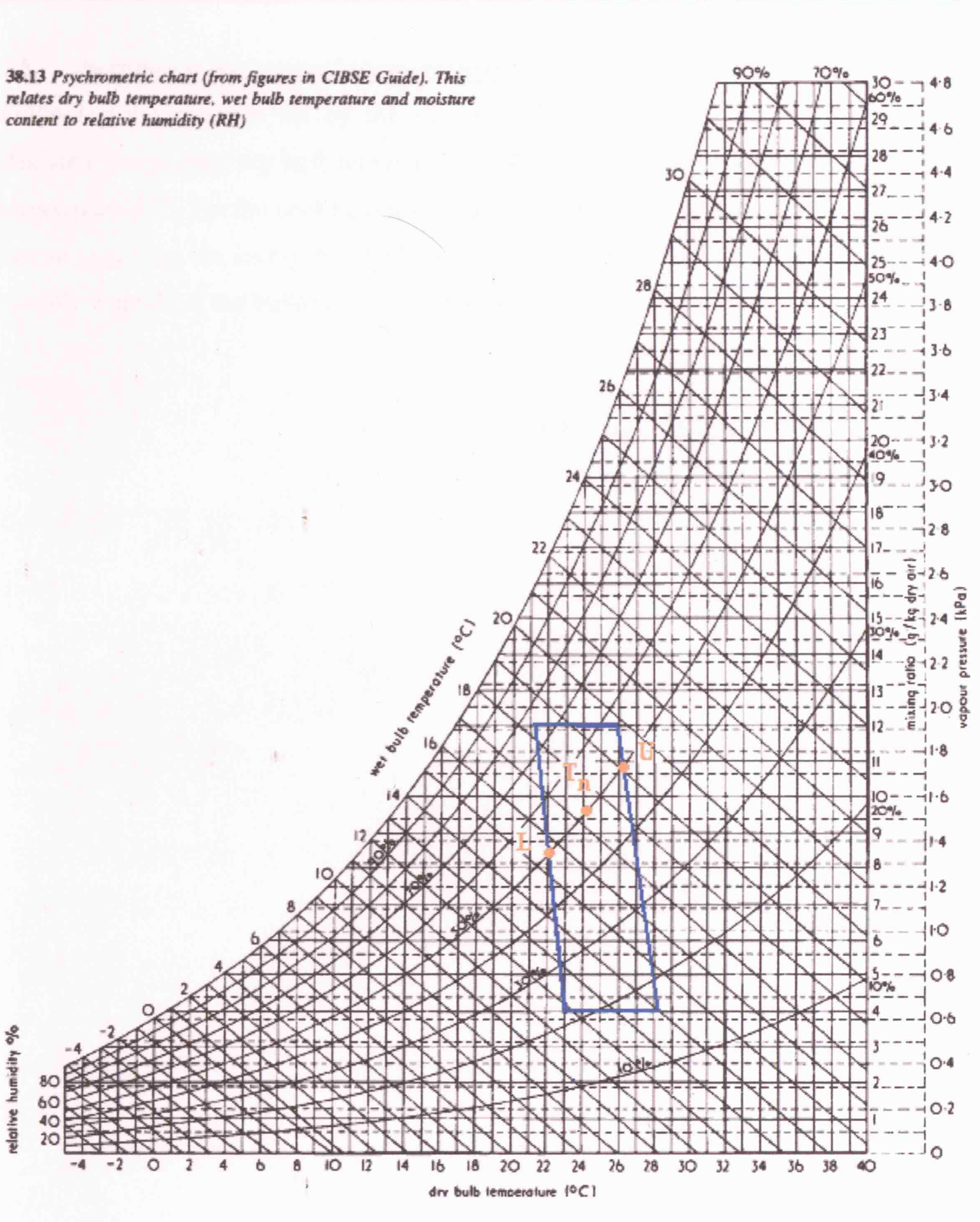


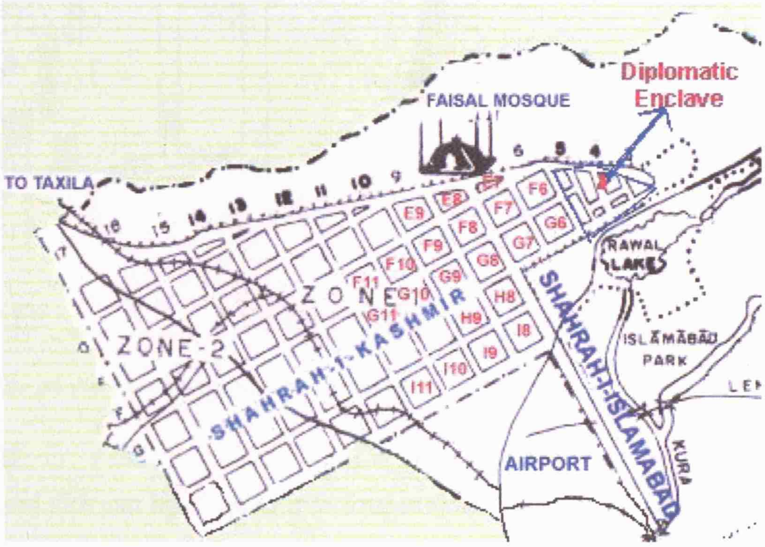
Figure 2.4: Comfort zone from the co-relation from the web bases article

2.5 Setting up the internal temperatures

Following the example set by the survey carried out by the energy commission of Pakistan. An internal dry bulb temperature of the building for the winter season would be targeted at 21°C. For the cooling season internal dry bulb temperatures were set under the advisement from the user of this building. Therefore the internal dry bulb temperature for the office area's of the building would be set at 23°C.

3.1 Profile of Islamabad

Islamabad is the capital city of Pakistan and is 518 meters above sea level. Geographical co-ordinates : 33° 40′ 0″ N 73° 10′ 0″ E



Total specified area of Islamabad 3626 Sq. Km

Climatic conditions in Islamabad are shown in the table below.

Seasons	Maximum Average	Minimum Average
Winter (Oct-Mar)	16.6 C	3.4 C
Summer (Apr - Sept)	34.2 C	24.4 C
Annual average	28.9 C	14.4 C

Table 3.1: Maximum and Minimum average temperatures in Islamabad

3.2 Profile on the company

Founded in 1967 Rastgar Engineering Co. Ltd. Are specialist manufacturer of bespoke parts for the automobile industry. It focuses on high grade cast and machined axle components. 70 % of it's production is exported out of Pakistan to European countries, they are one of the leading exporter in the Industrial sector of Pakistan.

There main production unit is situated in the Industrial sector I-9 of Islamabad. The map below presents its location in connection with the geography of the city.

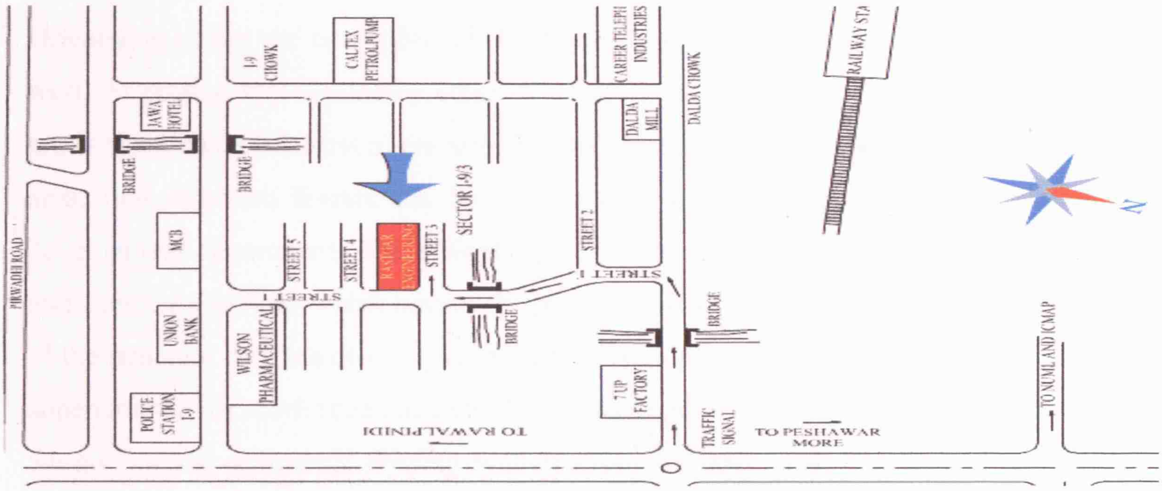


Figure3.1: Location of the site with respect to the geography of Islamabad

3.3 Existing building layout

The present layout of the proposed site can be divided into four major section according to it's functionality.

- The foundry
- The product research department
- The finishing work shop
- The administrative building
- The storage area

Layout of these sections with regards to the site plane can be seen from the figure below

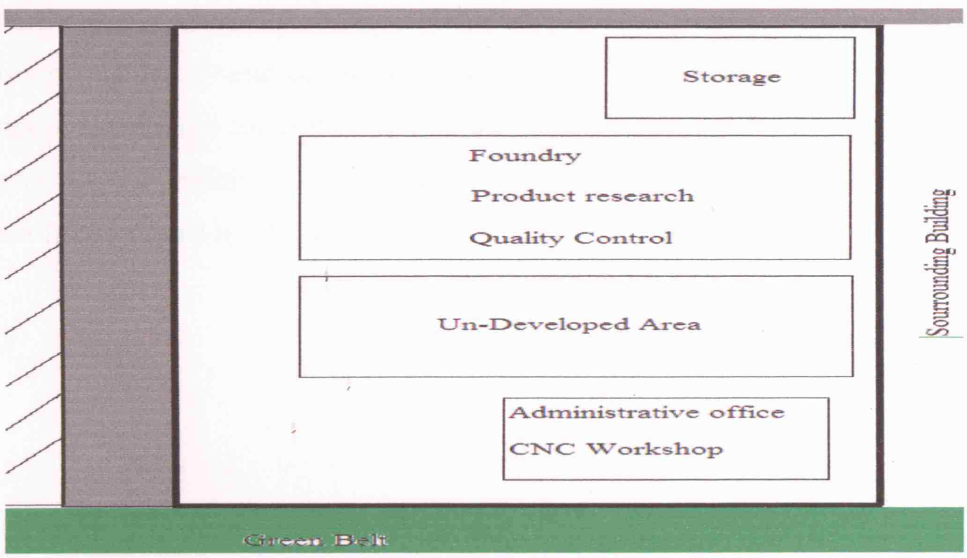


Figure 3.2: Current layout of the site

Orientation of the site is roughly 15° North-west, receiving solar gains from the east and west. At present it is shaded by other industrial units from the north and south and with green belt area on the west of the site. Presently there are three main structures on the site area; first structure houses the foundry, quality control department and the product development department. It is a single storey structure with the ceiling height of 9.7 m and a mezzanine floor which houses the product research department. The building fabric of the structure consists of single leaf brick with no plaster on both sides whereas it has a superstructure of reinforced concrete. It has single glaze windows with metal frame there are no external or internal shading available for the glazed area. The foundry area of the building is naturally ventilated whereas the quality control and the product research departments are naturally ventilated assisted by electrical fan.

The second existing structure is a relatively new building as compared with the building which houses the foundry. It is a single storey building with a basement. The basement of this building, houses centrally numerically controlled machines (CNC) which form the basic function of the finishing workshop. Ground floor is occupied by the administrative staff. The superstructure of the build is of reinforced concrete with cavity brick external walls without insulation and medium density plaster on both sides. Glazing of the structure is also a single glazed with tinted glass. Externally the windows are shaded by overhangs and internally venation blinds are provided in-order to counter the solar gains during summer. Frame of the windows are of aluminum. Ground floor environmental control is achieved through split air conditioner which runs through out the operational hours of the building. The finishing workshop in the basement again is naturally ventilated assisted by electrical fans.

3.4 Processes involved

Based on the functionality and processes involved the site can be divided into four zones which are described below.

i) The foundry

The foundry operates around the clock 24 hours, with following operations;

- Melting of pig iron
- Casting mould production

In the foundry iron and sheet metal scrap is melted through an induction furnace, the charge container of the furnace are open to the environment leading to heat loss to the environment through radiation. The process of mould production has two stages; first appropriate mixture of silica sand is mixed with sodium silicate which is than poured into wooden moulds to take appropriate shape. Second stage of mould production includes passing carbon-dioxide through the sand mixture making the mould hard and ready to be poured.

ii) Finishing workshop

Unfinished cast are processed through centrally numerically control machines (CNC) to their finished good level. These machines have their own cooling systems that keep the machine at appropriate working temperature. The machines heat gains of the environment are through the cutting, grinding and drilling processes of the CNC machines.

iii) Product development

At present the product development department is housed with in the main foundry building. Its main function is to co-ordinate with the clients and provides appropriate mould design to be used in the production line-up.

iv) Administrative building

Administrative building houses offices for marketing, finance department and executive room along with the conference rooms.

v) Storage areas

Storage area are located on the east side of the foundry and are used to store the raw material required by the foundry, mould manufacturing unit and also to store finished products to be shipped afterwards.

3.5 Proposed Building

For the purpose of investigation into the options of HVAC ventilation systems, building chosen would be a new addition to the building stock at the site. It is in process of its construction and lies between the existing structures of foundry building and the administration block. Structure will have three levels.

- Ground floor
- Mezzanine level
- First floor

Total covered area of the building is 3989.4 m^2 and the orientation of the building is same as that of the existing building that is 15° North West. This structure is parallel to the foundry and the administrative block, when fully constructed it will be approximately 9m away from both the existing building on the east and west of the proposed building, whereas it is shaded from the south by other industrial unit. Foot print of this building is 54.9 m by 24.4 m and the height of the building is 9.7 m.

Super structure of the building is of reinforced steel with external wall made up of double leaf brick with 50 mm air cavity and a plaster finish form the inside. Ceiling height of the ground floor is 6.7 m with an intermediate level the mezzanine floor. The floor height of the mezzanine floor is 3.7 m with standard wall height of 3 m. First floor starts at a level of 6.7m with standard wall height of 3 m. Partition wall in ground floor and the mezzanine level are of single leaf brick with plaster finish on both sides. Partitions of the first floor primarily will be off wooden ply board with 50 mm wooden frame except for the partition wall between the dinning hall, prayer area and the gym area where single leaf brick with plaster on both side are available. Salient features regard to environmental design of the building are as follow.

- Single glazing with aluminium frame.
- Walkways around the perimeter of the building for mezzanine and the first floor.
- Walkways act as overhangs for the external glazing of the building, width of the overhang is 2 m.
- External stairs are provided on the east side of the building to access the walkways.
- Stairs and stair well for the building are at the north west corner of the building.
- No insulation is provided for the structure.

Processes that will take place with in the building are as follow.

- Finishing work shop on the ground floor.
- Mezzanine level would house the R&D department and the quality control department.
- First floor will house offices for marketing and finance, conference rooms, executive room, guest room, prayer hall, gymnasium and dinning hall for the staff and the workers of the establishment.

There are two operational schedules for the building, one is for the staff of the finishing workshop and the other is for the administrative staff housed within the building. Ground floor where the finishing work shop will be in operation 24 hours a day with 3 working shifts each of 8 hours. Mezzanine level and the first floor of the building will be governed by the office hours of 8:00 am to 5:00 pm.

Apart from these general schedules there are some additional schedules given to the area on the first floor. These schedules relates to the occupancy of particular zone in the area.

Application of schedules for the areas such as the conference rooms and the guest rooms are not predictable as they are governed by the requirement of their use. For the purpose of simulation different conference rooms on the first floor have been given schedules at different time of the day. Maximum designed occupancy loads and the equipment loads are given in the table below. These loads are based on the information received from the consultant of the building.

Ground floor

Area	Occupancy	Load**		Equipment Load**	Schedule
		Sensible	Latent		
Workshop	30	2.44	7.77	28.1	24 hours

Table 3.2: Occupancy and equipment loads of the ground floor

Mezzanine Level

Area	Occupancy	Load**		Equipment Load**	Schedule
		Sensible	Latent		
R&D Department	14	10.15	7.6	11.9	0800-1700
Quality control	14	10.15	7.6	11.9	0800-1700

Table 3.3: Occupancy and equipment loads of the Mezzanine level

First Floor

Area	Occupancy	Load**		Equipment Load**	Schedule occupancy
		Sensible	Latent		
Large conference*	41	95.9	71.9	-	1400-1700
Executive room	7	18.6	13.9	5.8	0800-1700
Small conference1*	8	33.79	25.34	-	0900-1100
Small conference2*	8	33.79	25.34	-	1200-1300
Small conference3*	8	52.9	39.7	-	1500-1700
Guest room*	5	22.5	11.9	-	1200-1400
Media room	7	23.41	17.56	63.8	0800-1700
Marketing Dept.	40	17.9	13.5	38.4	0800-1700
Finance Dept.	16	23.85	16.4	42.7	0800-1700
Prayer Hall*	64	38.4	33.9	-	1300-1400
Gym*	20	14.93	29	-	1700-2000
Dining hall*	176	55.5	43.2	-	1300-1430

Table 3.4: Occupancy and equipment loads of the first floor

Notes:

1. CIBSE guide table 6.1 was used for typical sensible and latent loads of each activity for each zone.
2. Equipment loads were calculated using CIBSE guide Table 6.7 and 6.11.
3. Lighting load criteria set by using CIBSE guide.

* Schedules for these areas are hypothetical and depends on the their requirement.

** Units for these quantities are w/m^2.

3.6 Proposed HVAC design

This study aims to investigate the possibility of utilisation of waste heat from the foundry in-order to energise the absorption chiller. This in turn will provide the cooling load required for the summer season. The most prominent source of heat available in the foundry is the Induction furnace. Schematic diagram for HVAC utilising the waste heat can be seen from the figure below.

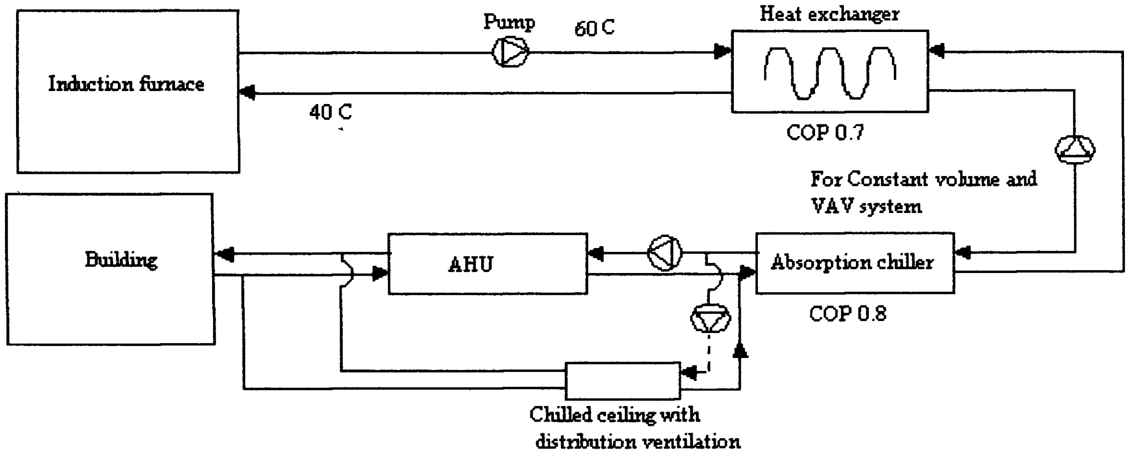


Figure 3.3: Schematic diagram for the HVAC system

The cooling circuit of the induction furnace at present utilizes the cooling tower to extract the excess heat from the furnace and is vented into the atmosphere. It is proposed that this cooling water be diverted from the cooling tower to the absorption chiller via a heat exchanger. Single stage absorption chillers are capable of operating with hot water within the range of 80-90°C. Therefore it will be worth the while to investigate the option of utilization of single stage absorption chiller. Coefficient of performance of the chiller has little significance as the system will be using the waste heat that would other wise be vented to the atmosphere.

The other aspect of this study is to investigate different forms of ventilation system and their impact on the energy consumption for the duration of cooling season. Ventilation systems under consideration are as follow.

- Constant Volume.
- Variable air volume (VAV).
- Chilled ceiling with displacement ventilation system.

3.7 Induction furnaces

3.7.0 Working of the 'Induction Furnace'

Induction furnaces consists of copper coil through which alternating current flows that produces a strong alternating magnetic field. This magnetic field in turns induces current in the metal contained in the furnace, the current induces in the metal produces heat which can melt the charge placed in the furnace. There are two basic types of induction furnaces.

- Channel induction furnace.
- Coreless induction furnace.

3.7.1 Channel induction furnace

In channel furnace the copper coil is wound around a laminated core of transformer steel. This core or the inductor is linked to a loop shaped channel formed in the refectory lining the inductor box. The box is attached to the main bath of the furnace and the ends of the channel loop connected with the main bath. When the channel is filled with enough molten metal to form a continuous circuit around the core, induced current can flow around it producing heat which is than transferred to the main bath of the furnace largely by the movement of the molten metal. Figure below illustrates the channel furnace.

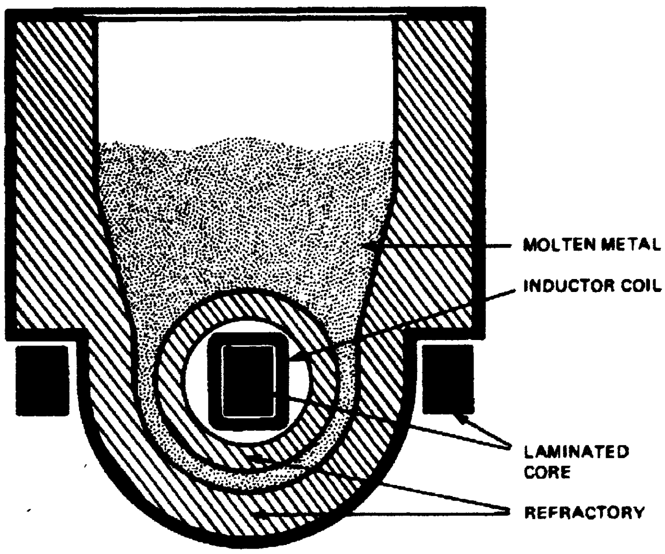


Figure 3.4: Channel Induction furnace
Source: Foundries Industry advisory committee 'Safe use of electric induction furnace' by health and safety commission and electricity council.

Since these furnaces requires molten metal before further heating could take place, they normally operate as holding, superheating and dispensing furnaces where the charge has been melted in other type of furnace.

3.7.2 Coreless furnaces

As the name suggests these furnaces has no core or inductor. Instead the crucible or refectory lining containing the charge is directly placed inside the furnace coil. For high electric efficiency the furnace charge and the coil should be as close together as possible, where as to contain the molten metal safely the refractory lining should be as thick as possible. Higher the operating frequency easier it is to start the furnace from cold. Typical medium range furnaces have a range of 200-3000 Hz. Figure below illustrates the configuration of a coreless furnace.

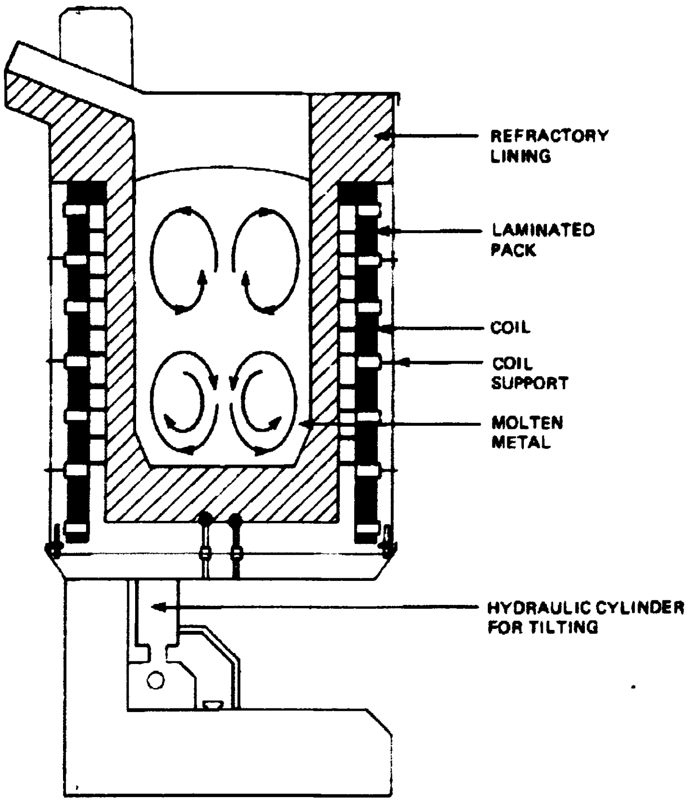


Figure 3.5: Coreless induction furnace
Source: Foundries Industry advisory committee 'Safe use of electric induction furnace' by health and safety commission and electricity council.

3.7.3 Cooling system for the induction furnaces

The coils of the induction furnaces have to be cooled down continuously in-order to maintain the electrical efficiency as well as to avoid meltdown of the copper coils. This is ensured by constructing hollow core coils through which cooling water flows. Some low frequency induction furnaces also employ air cooled inductors. Lining integrity is vital, the refractory is thin nest near the coil and if metal penetrates it the coil may melt. This will lead to molten metal and water explosion which can lead to fatalities.

The criteria of cooling water for the induction furnaces are as follow;

- Water should be of low electrical conductivity.
- Water should have little or no tendency to cause scaling or corrosion.
- Should be supplied at constant temperature.

There are two basic types of water circulating systems. First, is an open system where the extracted heat is transferred to the atmosphere through a cooling tower. For these systems regular checks are required to keep the contaminant levels low. Second type of water circulating systems are completely sealed where the extracted heat is transferred to the atmosphere through a suitable heat exchanger, therefore the possibility of contaminant can be avoided.

Inlet and outlet temperatures for the cooling water circuits are usually recommended by the supplier. The normal inlet temperature is 20°C or more, this is to avoid the formation of condensation on the copper coil or the power supply. The maximum outlet temperature for an open system is 70°C. For open system outlet water temperature more than 70°C can cause phenomena known as 'film boiling'. Water near the surface of the coil may boil and create a thin layer of stem insulating the water from taking up heat from the coil. This can lead to melt down of the coil causing molten metal/water explosion. This phenomenon can occur at an average temperature of only 70°C. This phenomenon can be avoided in two ways, either by keeping the inlet and outlet temperatures of the cooling water below 70°C or by using pressurised sealed systems. Pressurised system allows easier recovery of heat from the cooling water.

3.8 Possible heat recovery from the induction furnace

Furnace, currently in use at the site is a coreless induction furnace with an open water cooled system. The inlet and outlet temperatures for the given system are;

$$T_{in} = 40^{o}C$$

$$T_{out} = 60^{o}C$$

Mass flow rate for the given cooling system is;

Mass flow rate = 7.16 kg/s

Possible energy extraction for the given system can be calculated from the following equation.

$$Q = \dot{m}cp\Delta T$$

=>

$$Q = 598.81 \text{ kW}$$

Since the heat transfer in the proposed design will be through a heat exchanger, where as the efficiency of a shell tube heat exchanger is approximately at 70%. Therefore available heat that can be utilised for the absorption chiller is;

$$Q = 598.18 \text{ x } 0.7 = 418.73 \text{ kW}$$

3.9 Absorption Chiller

The most prevalent difference between absorption chiller and mechanical vapour compression chiller is that, absorption chiller are driven by heat energy whereas the vapour compression chiller operated with the help of mechanically driven compressors. Figure3.6 and 3.7 y illustrates the difference between the two cooling systems.

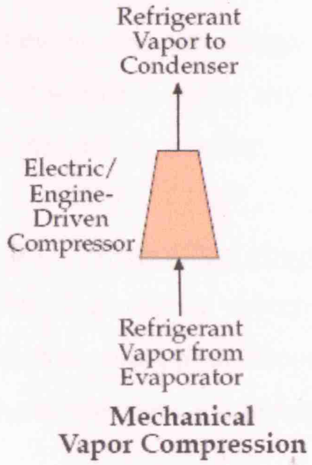


Figure 3.6: Mechanical vapour cycle

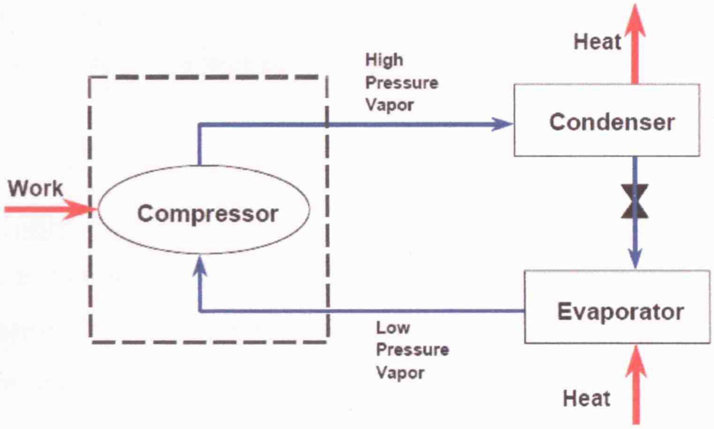


Figure3.7: Absorption cooling cycle

In absorption system, the "thermal" compressor consists of the generator, absorber, pump and heat exchanger. The evaporator allows the refrigerant to evaporate and to be absorbed by the absorbent. In this process heat is extracted from the building through the water circuit running from the chiller to the air handling units. The combined fluids (the refrigerant and the absorber) then goes to the generator, which is heated by the gas, steam or hot water (incase of single effect), driving the refrigerant back out of the absorbent. The refrigerant then goes to the condenser to be cooled down to a liquid state, while the absorbent is pumped back to the absorber. The cooled refrigerant is released into the evaporator through an expansion valve where it is ready to extract more heat from the building. Most common combination of refrigerant and absorber for absorption chillers are

- Lithium bromide (LiBr) and water.
- Ammonia NH_4 and water.

The lithium bromide and water systems uses lithium bromide as absorber and water as refrigerant, whereas in ammonia and water system ammonia is the refrigerant and water is the absorber. General classifications of the absorption chiller are;

- Single effect.
- Double effect.

They are also sub-categorized as direct and in-direct fired system. In direct fired system heat source is gas or any other form of fuel. In-direct systems utilize waste heat sources or steam from a boiler.

3.9.1 Single effect absorption chiller

The single-effect absorption cycle has four major components of the refrigeration machine evaporator, absorber, generator and condenser. Schematic diagram in relation to the temperature and pressure can be seen from the figure below.

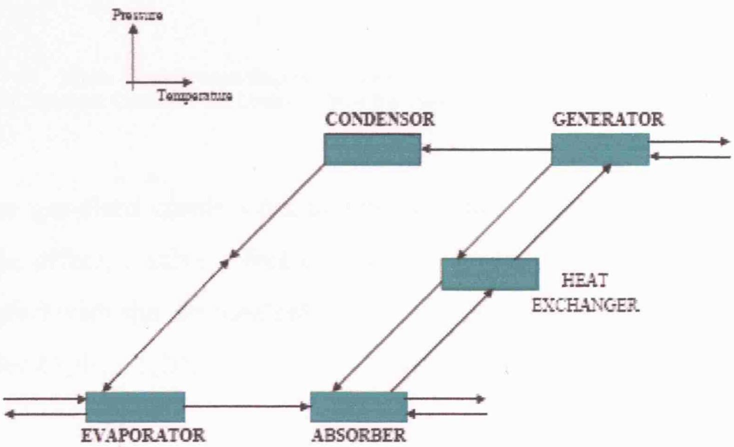


Figure 3.8: Single effect schematic diagram

Source: 'Absorption chillers' Southern California Gas Company, New Building Institute, Advance design guideline series, November 1998.

Single-effect LiBr/H2O absorption chillers use low pressure steam or hot water as the heat source. The water is able to evaporate and extract heat in the evaporator because the system is under a partial vacuum. The thermal efficiency of single-effect absorption systems is low, between the ranges of 0.60 to 0.80 COP.

3.9.2 Double effect absorption chiller

Double effect chiller also follow the same principal of cooling as in single effect, difference in their processes is that the double effect chiller has two condensers and two generators to allow for more refrigerant boil-off from the absorbent solution. Figure below represents the double effect absorption cycle on a Pressure-Temperature diagram

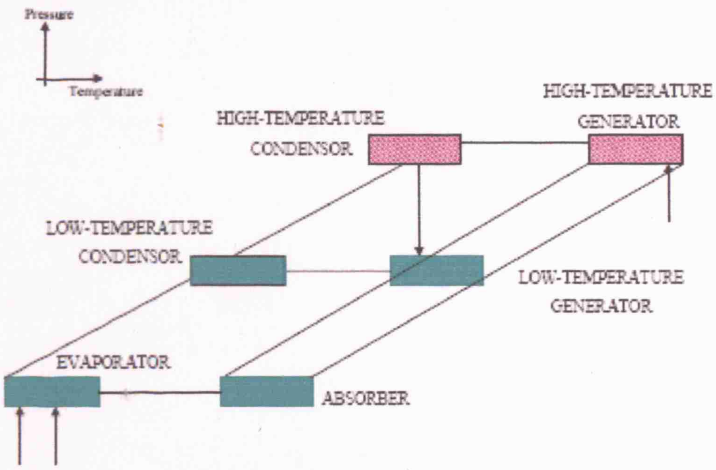


Figure 3.9: Schematic diagram of double effect chiller
Source: 'Absorption chillers' Southern California Gas Company, New Building Institute, Advance design guideline series, November 1998.

These systems use gas-fired combustors or high pressure steam as the heat source. As compared to single effect, double effect chiller have higher co-efficient of performance that can be compared with the mechanical vapor compression cycle efficiency. Typically double effect chiller COP is 1.20.

3.10 Alternate to Single effect absorption chiller

An alternate to absorption chiller is an adsorption chiller that is capable of operating at temperature as low as 50°C, while producing chilled water at temperatures less than 3.33°C. Adsorption chiller works on same principle as the absorption chiller, difference is the thermodynamic relation between the absorbent and the refrigerant for the chiller.

Figure 3.10: Adsorption chiller

Adsorption chiller uses water as refrigerant and permanent silica gel as absorbent. The evaporator section cools the chilled water by the refrigerant (water) being evaporated by adsorption of the silica gel in one of two adsorbent chambers. The hot water regenerates the silica gel in the second of the two adsorbent chambers. The water vapor released from the silica gel by the hot water will be condensed in the condenser section which is cooled by cooling water. The absorption chiller has a very low operational cost, 360 kW system only requires 0.4 kW of electrical energy to run the pumps.

3.11 Ventilation systems

Different ventilation systems covered in this study to find appropriate regimes for the HVAC system, in a building for hot climate are as follow.

- Constant volume.
- Variable air volume.
- Chilled ceiling with under floor air supply or displacement ventilation.

3.11.1 Constant volume ventilation systems

These are high velocity all air systems where air supplied to different zones of the building through terminal units placed in each of the zone in the building. An example for air distribution for this type of system is shown below.

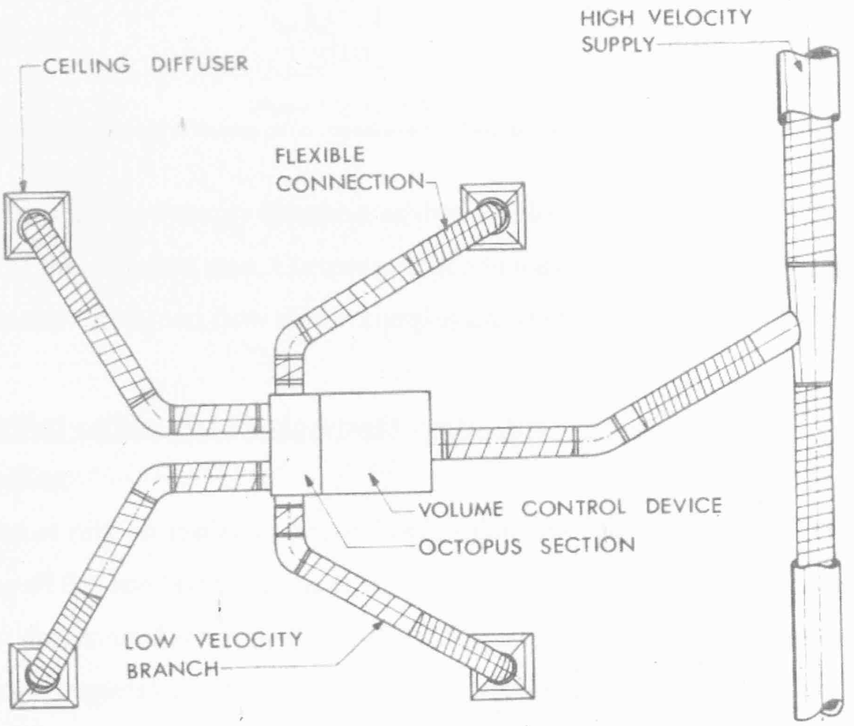


Figure 3.11: Example of a CAV system
Source: Faber and kell's 'Heating and air conditioning of building', seventh edition.

The required quantity of air providing the desired cooling for the zone is controlled through pressure reducing valves such as damper which are fitted in each terminal units of the building. In this system the cooling air is provided by means of cooling coil of the air handling unit, through which chilled water from the chiller flows.

3.11.2 Variable air volume system

These systems are also high velocity air systems. Variable volume systems are refinement to the constant all air system, where the changes in the load conditions of the zone are not catered by adjusting the temperature of the supplied air. In these systems change in local loads are catered for by adjusting the volume through the terminal unit while keeping the temperature of the supplied air constant. Figure below shows an example of a variable air volume control unit.

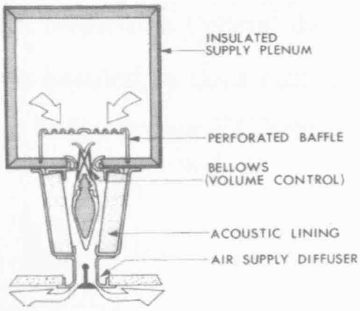


Figure 3.12: Variable air volume terminal unit
Source: Faber and kell's 'Heating and air conditioning of building', seventh edition. Page 359 figure 14.13.

These systems are less energy intensive as they are designed to operate with variable load condition of the supplied area. Current practice volume flow rate can be reduced to 20% of the maximum designed flow rate to compensate the variable load conditions.

3.11.3 Chilled ceiling and displacement ventilation system

Chilled ceiling

These systems rely on radiative cooling rather than convective cooling of all air system. The ceiling of the conditioned zone is supplied with chilled water for the removal of heat gains from that zone. The air distribution for these systems has sole purpose of providing fresh air for occupancy and humidity control. Essential features of this system are.

- Ventilation air is to be conditioned such that the dew point is below the surface temperature of the ceiling.
- Air flow rates are less than the conventional convective cooling, as the ventilation system provides air for occupancy.

These systems are less energy intensive as there are no intermediate cooling systems between radiative panel and the chiller. Secondly because the cooling water is not chilled to 7°C but the temperature is kept with in the range of 17°C to 19°C.

Displacement ventilation

In these systems air is generally supplied through false floor at a very low velocity (about 0.5 m/s) which is necessary to avoid sensation of draught. There are effectively two types of floor outlets for displacement ventilation system; the twisted pattern and the straight pattern. Air quantity that can be handled by such outlets is about 12 l/s and the supply temperature of the air should not be lower than 5°C below the occupied zone temperature.

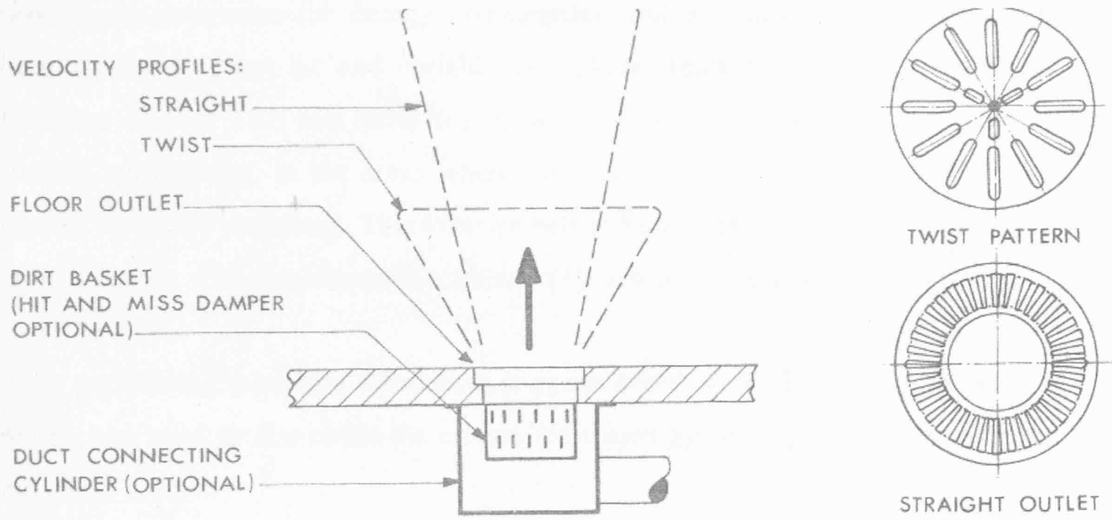


Figure 3.12: Typical outlets for displacement ventilation
Source: Faber and kell's 'Heating and air conditioning of building', seventh edition.

Energy simulation of the case study

4.0 Introduction

In order to investigate the cooling loads and the energy consumption of the proposed building, the following energy simulation software's were used namely;

- TAS NG

Initially TAS simulation was carried out in-order to determine the cooling load of the building. This helped to identify the load capacity of the chiller required to maintain the comfort temperature as specified in the chapter 2 (the thermal comfort of the building located in the climatic zone IV of Pakistan). After running the simulation in TAS for the whole year using the weather file on Islamabad (where the building is located), a macro was run to determine the energy consumption and the carbon dioxide emission of the building for constant air and variable air volume ventilation system to be used in the building. Further TAS was used to simulate the internal condition as well as the internal surface temperature, in the areas where the chilled ceiling with displacement ventilation system was to be simulated. This exercise helped us to determine the possibility of adopting chilled ceiling with displacement ventilation system for climate seen in Islamabad.

After performing the initial simulation, a macro based on the TAS TBD file was run. This macro was used to determine the carbon emissions and energy consumptions of the base model.

4.1 Simulation through TAS NG

TAS is a suite of software products, which simulate the dynamic thermal performance of buildings and their systems. The main module is TAS Building Designer, which performs dynamic building simulation with integrated natural and forced airflow. It has 3D graphics based geometry input that includes a CAD link

Energy simulation in TAS is done in three steps, first by making a 3D model in TAS 3D and specifying the studied zone of the building. After making the 3D model it is exported to the dynamic simulation program for TAS called TBD file. Here information such as;

- Weather file.
- Characteristic of building elements.
- Internal condition for the zones to be studied.
- Scheduling of the internal condition.
- Operation of the apertures/windows is given.
- Shading devices for the windows.
- Inter-zonal air movement.

The checked inputs of the model exported from the TAS3D, and were used for the model in TBD file after which simulation can be carried out for the building. The last step in the energy simulation is to run the simulation for the weather file used, it could either be for the whole year or for specific time in the year. Results for this simulation can be interrogated in the TSD file of TAS.

4.2 Base Model

A 3D model of the proposed building was created in TAS3D, as described in the chapter 4 section 'proposed building'. The North façade of the building can be seen from the figure given below. On the east side of the building is the existing structure of the foundry whereas on the west side of the building we have a single storey administrative building.

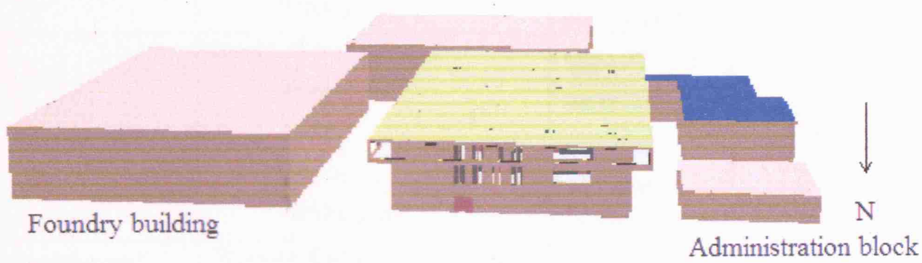


Figure4.1: Orientation of the proposed building

This model with its zones were exported in to the dynamic simulation program for TAS by making a TBD file.

4.3 Setting up of the TBD file for the base model

After exporting the model from TAS3D, appropriate inputs were given these inputs are given below.

1) Weather file

Weather file	Islamabad

Table 4.1: Weather file

2) Building elements

Building elements	Construction	Material used	Width 'mm'	U-value 'W/m^2 °C'
External wall	Inside: White paint	am1s\38	0.1	Horizontal: 1.032
	Light plaster	am1plast\1	25.0	
	Brick	am1brick\1	105.0	
	Cavity	am1 cav\5	50.0	
	Brick	am1 brick\1	105.0	
Internal wall	Inside: White paint	am1s\38	0.1	Horizontal: 2.278
	Plaster	am1plast\1	25.0	
	Brick	am1brick\1	105.0	
	Plaster	am1plast\1	25.0	
	White paint	am1s\38	0.1	
Partition wall	Wooden frame with ply board	am1wood\33	50.0	Horizontal:1.879
External wall	Inside: Blinds	am1blind\2	1.0	Horizontal:5.032
	Air gap	am1cav\11	15.0	
	6mm Grey glass	am1plik\12	6.0	
Internal windows	Inside: Blinds	am1blind\2	1.0	Horizontal:5.032
	Air gap	am1cav\11	15.0	
	6mm clear glass	am1plik\2	6.0	
Window frame	Aluminum	am1metal\1	50.0	Horizontal:5.848
Doors	Wooden frame with ply board	am1wood\33	50.0	Horizontal:1.879
Door frames	Wooden frame	am1wood\33	50.0	Horizontal:1.879
Ground floor gates	Steel	am1metal\4	5.0	Horizontal:5.848
Ground floor	Inside: Terrazzo	am1tile\13	13.0	Upwards:7.092
	Screed	am1concd\9	50.0	
	Concrete	am1concd\1	150.0	
	Crushed bricks	am1aggr\4	75.0	
	Clay	am1soil\1	10000.0	
Upper floor/ceiling	Inside: Tile	am1tile\12	15.0	Upwards: 2.77
	Screed	am1concd\1	50.0	
	Concrete	am1concd\9	100.0	
	Plaster	am1plast\11	25.0	
	White paint	am1s\38	0.1	
Roof	Inside: White paint	am1s\38	0.1	Upwards:3.062
	Plaster	am1plast\11	25.0	
	Concrete	am1concd\1	100.0	
	Screed	am1concd\9	50.0	
	Roof felt	am1asph\9	5.0	
	Asphalt	am1asph\6	5.0	

Table 4.2: Building elements

These building elements are based on typical 'Heavy weight' construction carried out in Pakistan.

3) Internal conditions for the while building

Ground Floor:

Occupancy*;

Area	Occupancy	Load**		Equipment Load**	Occupancy Schedule
		Sensible	Latent		
Workshop	30	2.44	7.77	28.1	24 hours

Table 4.3: Occupancy load for the ground floor

Thermostat***;

Upper limit '°C'	Lower limit '°C'	RH% upper limit	Schedule
23	21	60	24 hours

Table 4.4: Thermostat for the ground floor

Emitter**;

For Cooling	Air conditioning 'Convective heating'
For Heating	Air conditioning 'Convective heating'

Table 4.5: Emitter used for the ground floor

Mezzanine Level

Occupancy*;

Area	Occupancy	Load**		Equipment Load**	Occupancy Schedule
		Sensible	Latent		
R&D Department	14	10.15	7.6	11.9	0800-1700
Quality control	14	10.15	7.6	11.9	0800-1700

Table 4.6: Occupancy load for the mezzanine level

Thermostat***;

Upper limit '°C'	Lower limit '°C'	RH% upper limit	Schedule
23	21	60	0800-1700

Table 4.7: Thermostat for the mezzanine level

Emitter**;

For Cooling	Air conditioning 'Convective heating'
For Heating	Air conditioning 'Convective heating'

Table 4.8: Emitter used for the mezzanine level

First Floor:

Occupancy*;

Area	Occupancy	Load**		Equipment Load**
		Sensible	Latent	
Large conference*	41	95.9	71.9	-
Executive room	7	18.6	13.9	5.8
Small conference*	8	33.79	25.34	-
Small conference*	8	33.79	25.34	-
Small conference*	8	52.9	39.7	-
Guest room	5	22.5	11.9	-
Media room	7	23.41	17.56	63.8
Marketing Dept.	40	17.9	13.5	38.4
Finance Dept.	16	23.85	16.4	42.7
Prayer Hall*	64	38.4	33.9	-
Gym	20	14.93	29	-
Dining hall*	176	55.5	43.2	-

Table 4.9: Occupancy load for the first floor

Thermostat***;

Upper limit '°C'	Lower limit '°C'	RH% upper limit	Schedule
23	21	60	0800-1700

Table 4.10: Thermostat for the first floor

Emitter**;

For Cooling	Air conditioning 'Convective heating'
For Heating	Air conditioning 'Convective heating'

Table 4.11: Emitter used for the first floor

Notes:

* All the occupancy numbers for each zone of the building were provided by the design consultant for the company. Thermostat settings for each zone are based on the ongoing standard practice in Pakistan.

** Emitters for each zone for the base model were chosen to simulate the effect of constant air volume system.

*** For the cooling season internal dry bulb temperatures were set under the advisement from the user of this building. Whereas for the heating season were set out according to the survey carried out by the energy commission of Pakistan

4) Fresh air ventilation rates for different area's of the building:

Fresh air change rates were calculated on the recommended guidance from CIBSE for the mixing of outside air with the re-circulated air from the different zones of the building. This is to avoid supplied air to the zone becoming stale and causing building sickness.

Ground floor:

Area	Occupancy	Fresh air ventilation 'ach'
Workshop	30	0.67

Table 4.12: Fresh air for ground floor

Mezzanine level:

Area	Occupancy	Fresh air ventilation 'ach'
R&D Department	14	2.44
Quality control	14	2.44

Table 4.13: Fresh air for mezzanine level

First floor:

Area	Occupancy	Fresh air ventilation 'ach'
Large conference	20	5.60
Executive room	7	2.40
Small conference	8	4.40
Small conference	8	4.40
Small conference	8	7.00
Guest room	5	3.10
Media room	7	3.10
Marketing Dept.	40	2.30
Finance Dept.	16	3.10
Prayer Hall	64	4.70
Gym	20	2.60
Dining hall	176	10.00
Common area	9	0.32

Table 4.14: Fresh air for the first floor

5) Lighting load

Lighting loads for each zone were calculated by keep in mind the activity in that area and also in accordance with the CIBSE guide

Ground floor;

Area	Lighting load 'W/m^2'
Workshop	8

Table 4.15: Lighting load for the ground floor

Ground floor lighting loads were kept low because CNC machines are provided with their own luminance. This luminance is due to the input screens for each CNC machines.

Mezzanine level;

Area	**Lighting 'W/m^2'**
R&D Department	12
Quality control	12

Table 4.16: Lighting load for the mezzanine level

Lighting load of 12 W/m^2 is a standard lighting load for an office.

First floor;

Area	**Lighting 'W/m^2'**
Executive room	12
Finance Dept.	12
Marketing Dept.	12
Media room	12
All the other zones on first floor	8

Table 4.17: Lighting level for the first floor

After inputting the above mentioned parameters, a simulation was run for the whole year. From the results maximum cooling and heating loads for the building were determined.

4.4 Annual loads for the 'Base Model'

After simulating the base model, a macro given in the TAS database named 'Annual load' was run. This macro uses the file that generates the simulation results for a design model 'TSD' and creates graphs and tables in 'Microsoft Excel'. By running this macro, following graphs and tables for the entire project can be obtained.

1. Annual loads, monthly loads and peak loads for the entire project. Annual and monthly loads are given in 'kWh' whereas the peak loads are given in 'kW'.
2. Weekly loads for the entire project in 'kWh'.
3. Daily loads for the entire project in 'kWh'.
4. Hourly sensible loads in 'kW'.
5. Hourly humidification and de-humidification loads.
6. Annual, monthly, weekly and peak load graphs in 'kWh'.

See 'Appendix B' to setup the 'annual load' macro.

4.5 Carbon emission calculation for 'CAV' and 'VAV'

After performing the annual load calculation, another macro from the TAS library was run which looks into the carbon emissions and energy consumption of the designed model. For this purpose an improved version of the proposed build was created. This was done by using 'Carbon emission calculation method' macro given in TAS database library. This macro compares the designed building against a building that complies with 'elemental method'; this building mode is called the notional or nominal model. The model only uses four building elements for the external surfaces of the building which complies with 'Table 4' of Part L2. All the windows and doors that exists in the design model are removed in nominal model and replaced with the correct proportion of glazing appropriate for the orientation of each surfaces as set out in the 'Table 4' of Part L2. After making a nominal model the simulation was run for the whole year. Once the simulation for the nominal model was completed 'Part L2' macro was run, from this macro 'CECM' (carbon emission calculation method) tab was chosen.

CECM was setup by following the tutorials given in the TAS manager . Results obtained from 'CECM' were based on two different building service systems and are given in the 'Chapter 5'

- Constant air volume HVAC system.
- Variable air volume HVAC system.

4.6 Chilled ceiling and Displacement ventilation system

After performing simulations for constant air volume and variable air volume systems, another ventilation system ,was investigated 'chilled ceiling and displacement ventilation'. For this system a simpler model was created but the internal conditions given to this model were similar to that of the original proposed building design. This model was created in-order to determine whether such system could be adopted for hot climates with higher internal gains.

Foot print for this model was 10m by 10m whereas the height of the structure was maintained as that of the original building that is 9.7m. In-order to simulate the effect of chilled ceiling an additional floor was created on top of the first floor of the model.

Similarly to simulate displacement ventilation for the first floor an additional floor was added on top of the mezzanine level and by introducing an IZAM (inter-zonal air movement) from this floor to the first floor. For the purpose of simulating the displacement ventilation, void was introduced in the floor of fist floor and the ceiling of the floor in between the first floor and the mezzanine level. Additional windows were added to the first floor and the floor through which displacement ventilation was to be simulated. Building elements for this model were similar to that of the original building. Following requisites were followed for the simulation of chilled ceiling with displacement ventilation.

1. Surface temperature of the ceiling was to be maintained at 19°C.
2. This would simulate the radiative cooling effect of the ceiling.
3. Internal temperature for the displacement ventilation floor should not be below 5°C than the temperature to be maintained in the first floor.
4. Condensation should not occur on the surface of the chilled ceiling.
5. Fresh air supply should be provided through displacement ventilation.
6. This ventilation system would be applied to the office area and the conference rooms of the first floor.
7. Temperature would be maintained at 23°C.

Results for this simulation are investigated in the following chapter.

5.0 Simulation results

The models described in the previous chapter were setup and run; results obtained from these simulations were investigated for the desired parameter. These parameters include;

- Required cooling loads for the base model.
- Chiller capacity sizing and the possibility of utilising the extracted heat from the induction furnace in the existing building as a source of energy input for the chiller.
- Carbon emissions and the energy consumption for the base model.
- Carbon emission and the energy consumption of the improved nominal model.
- Comparison between the base model and the nominal model.
- Performance of the chilled ceiling and displacement ventilation system.
- Building fabric performance.

5.1 Results for base model

After simulating the model for the whole year, maximum cooling and heating loads for the studied area were taken. These maximum loads corresponds to the peak loads of that area for a specific time in the weather file, these do not corresponds to the design cooling or heating loads for the building. Design loads for the chiller were calculated by introducing a part load factor for the chiller. Standard part load practice at which chiller are designed is 20%. Therefore by adding 20% to the peak loads of the building, design capacity for the chiller was calculated. Table 5.1 represents the peak and design loads required for the building to maintain specific internal condition for each zone of the building, as described in the previous chapters. These values do not include the pump, AHU and the water circuit efficiencies. These variables were studied in the 'CECM' simulation for 'CAV' and 'VAV' ventilation system to determine the energy consumption of the systems.

Building levels	Peak load 'kW'		Design load 'kW'	
	Cooling	Heating	Cooling	Heating
Ground floor	117.7	122.7	141.24	147.24
Mezzanine level	17.1	6.57	20.52	7.884
First floor	253.5	81.6	304.2	97.92
Total 'KW'	**388.3**	**210.87**	**465.96**	**253.044**

Table 5.1a : Peak and design loads for the building

Building levels	Peak load 'kW'		Design load 'kW'	
	Cooling	Heating	Cooling	Heating
Ground floor	89.3	0	107.2	0
Mezzanine level	15.1	4	18.12	4.8
First floor	215.1	52.302	258.12	62.76
Total 'KW'	**319.45**	**56.304**	**383.44**	**67.56**

Table 5.1b: Peak and designed loads for nominal building

Energy consumption graph and table for the whole year of the base model are given by 'figure 5.1'.

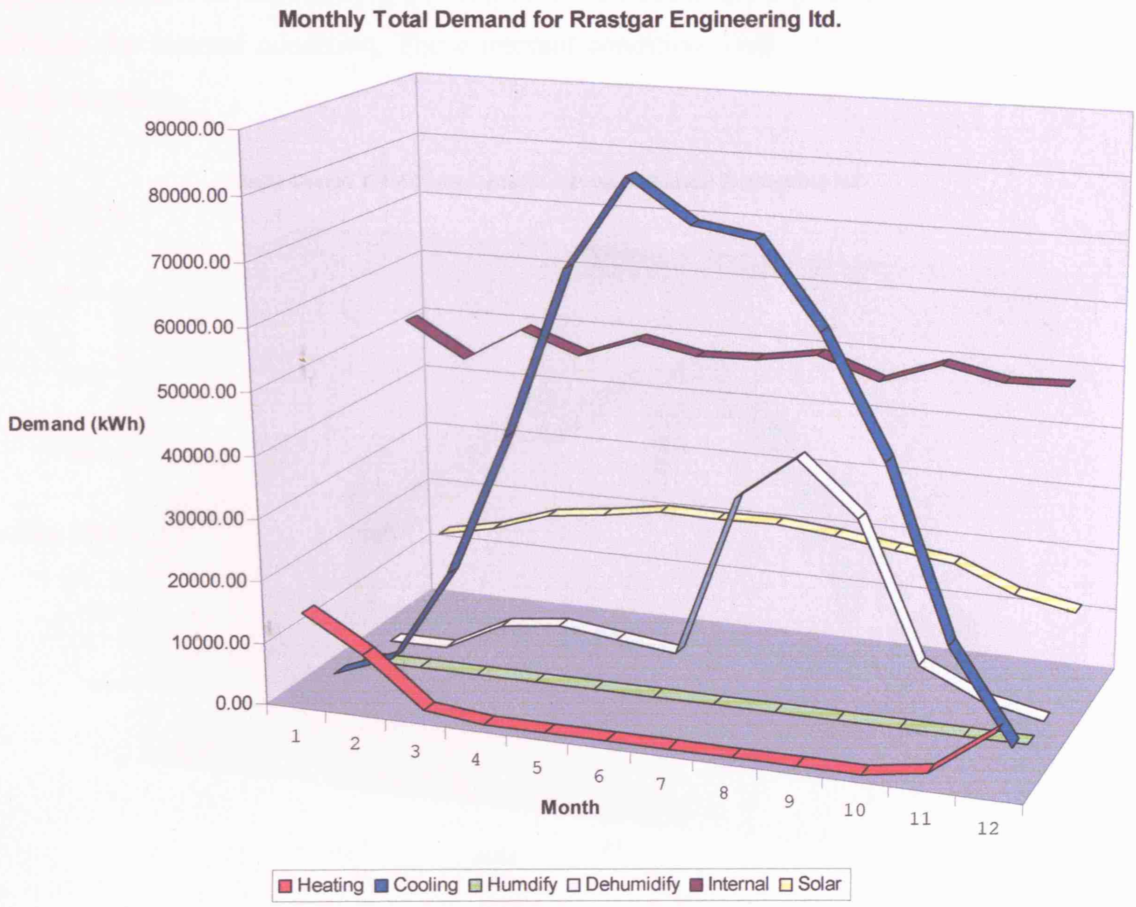


Figure 5.1: Monthly energy consumption for the whole building

	Heating in 'kWh'	Cooling in 'kWh'	Dehumidify in 'kWh'
Whole building	35219.71	505328.31	126514.12

Table 5.2 : Annual consumption

These energy consumptions are for the peak loads for the building rather than the design load for the chiller capacity.

5.2 CECM results for designed building with 'Constant air volume system'

Results obtained by running the 'Carbon emission calculation method' macro represents the performance of the building in relation to it's building services system adopted to maintain the internal condition, These internal condition were specified in chapter 4 of this dissertation.

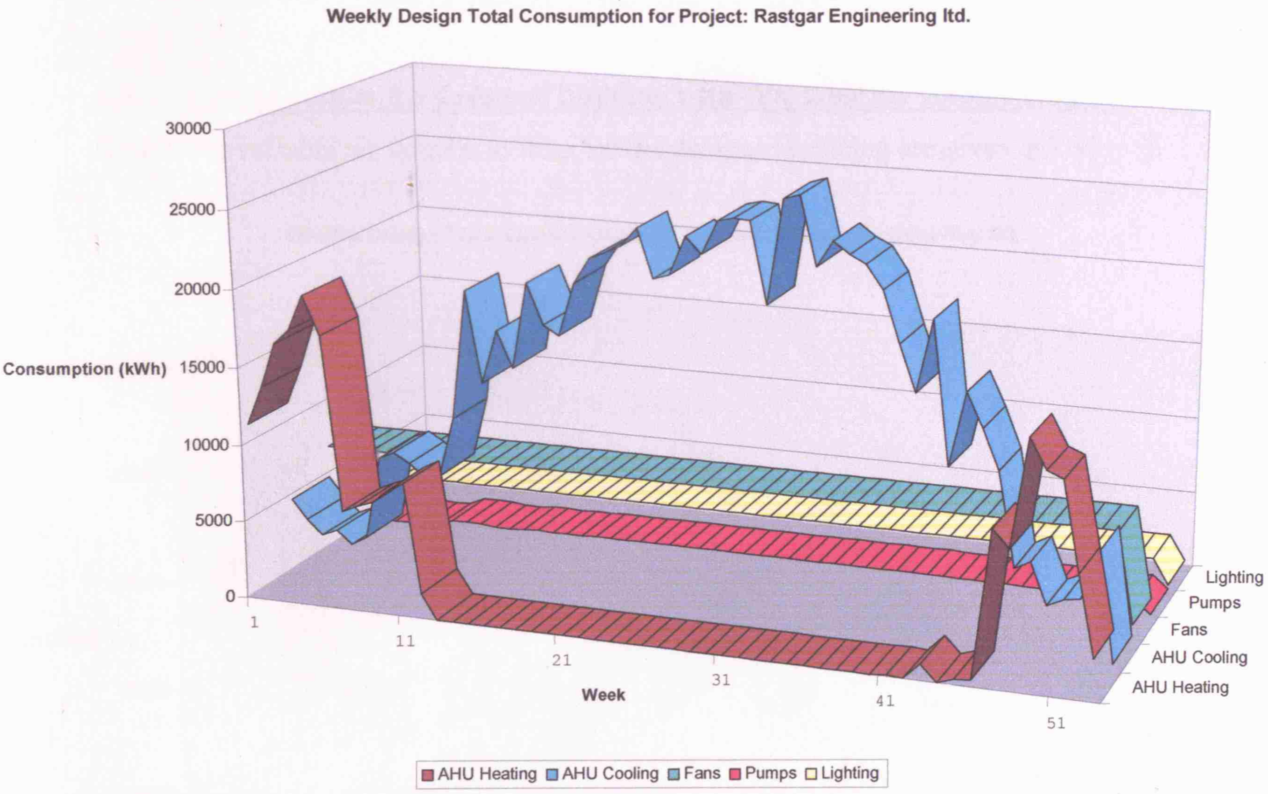


Figure 5.2: Weekly consumption of the designed building for CAV system

	Central plant	Designed building
Consumption	AHU Heating	82.46206151
	AHU Cooling	318.955157
	Fans	144.9899931
	Pumps	19.20176621
	Lighting	40.40033793

Total	606.0093158	kWh/m^2

Table 5.3: Annual energy consumption for 'CAV' systems

	Central plant	Designed building
Carbon Emissions	AHU Heating	4.37048926
	AHU Cooling	36.04193274
	Fans	16.38386923
	Pumps	2.169799581
	Lighting	4.565238186
	Total	63.53132899 kg/m^2

Table 5.4: Annual carbon emissions for 'CAV' systems

5.3 CECM results for designed building with 'Variable air volume system'

Results for variable air volume system for the designed building are given below.

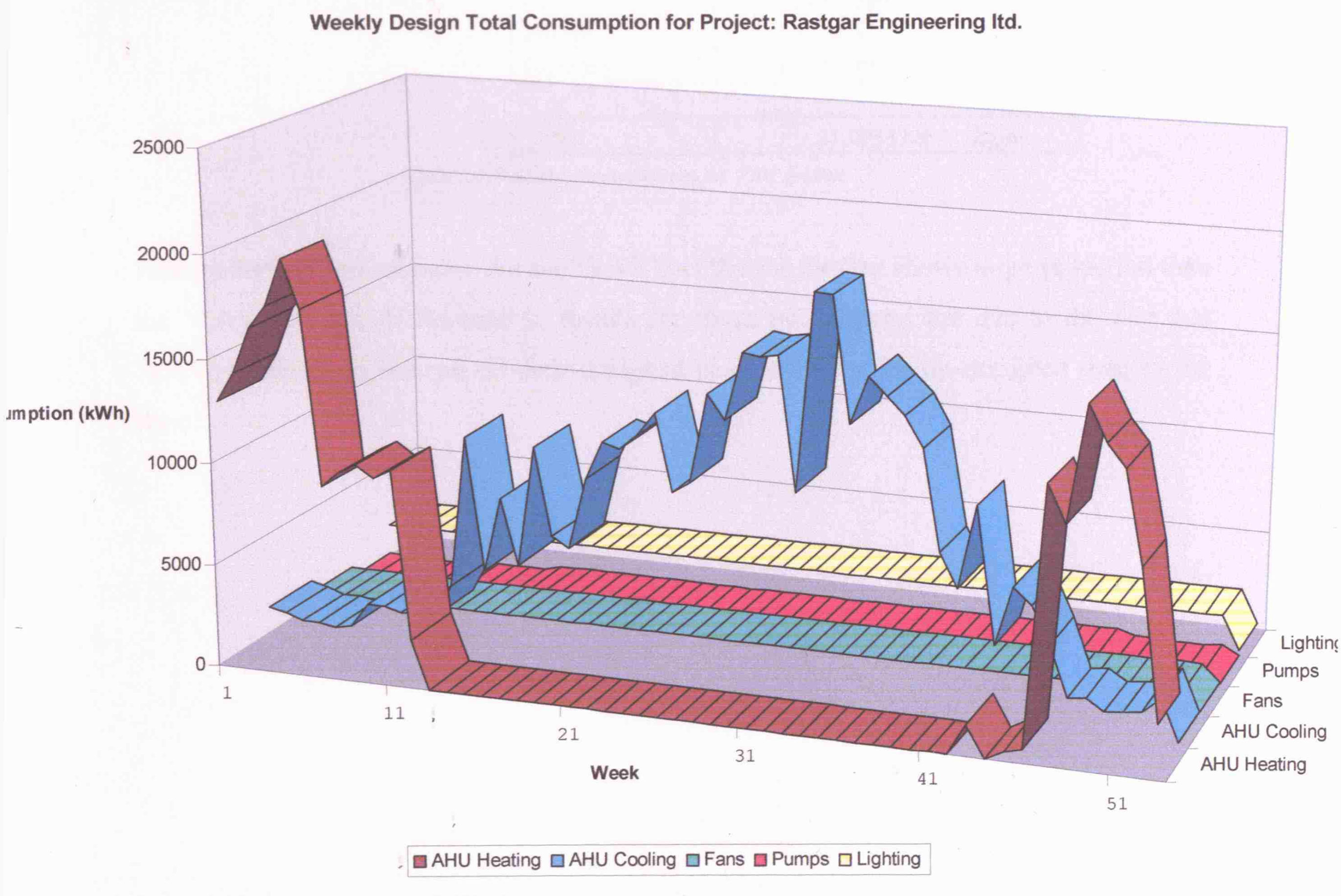


Figure 5.3: Weekly consumption of the designed building for VAV system

	Central plant	Designed building
Consumption	AHU Heating	93.54208879
	AHU Cooling	158.5475566
	Fans	19.72728905
	Pumps	12.61501084
	Lighting	40.40033793
	Total	324.8322832 kWh/m^2

Table 5.5: Annual energy consumption for 'VAV' systems

	Central plant	Designed building
Carbon Emissions	AHU Heating	4.957730706
	AHU Cooling	17.91587389
	Fans	2.229183662
	Pumps	1.425496225
	Lighting	4.565238186
	Total	31.09352267 kg/m

Table 5.6: Annual carbon emissions for 'VAV' systems

Energy and carbon emission for the 'VAV' ventilation system shows large reduction than the 'CAV' system. Difference in results for these two systems are due to the fact that 'VAV' systems do not run on their designed peak loads for the un-occupied time of the zone.

5.4 CECM results for Nominal building with 'Constant air volume system'

Nominal building is the improved version of the base model. Building fabric elements such as walls, glazing and roof are in accordance with the Table 4 of Part L2.

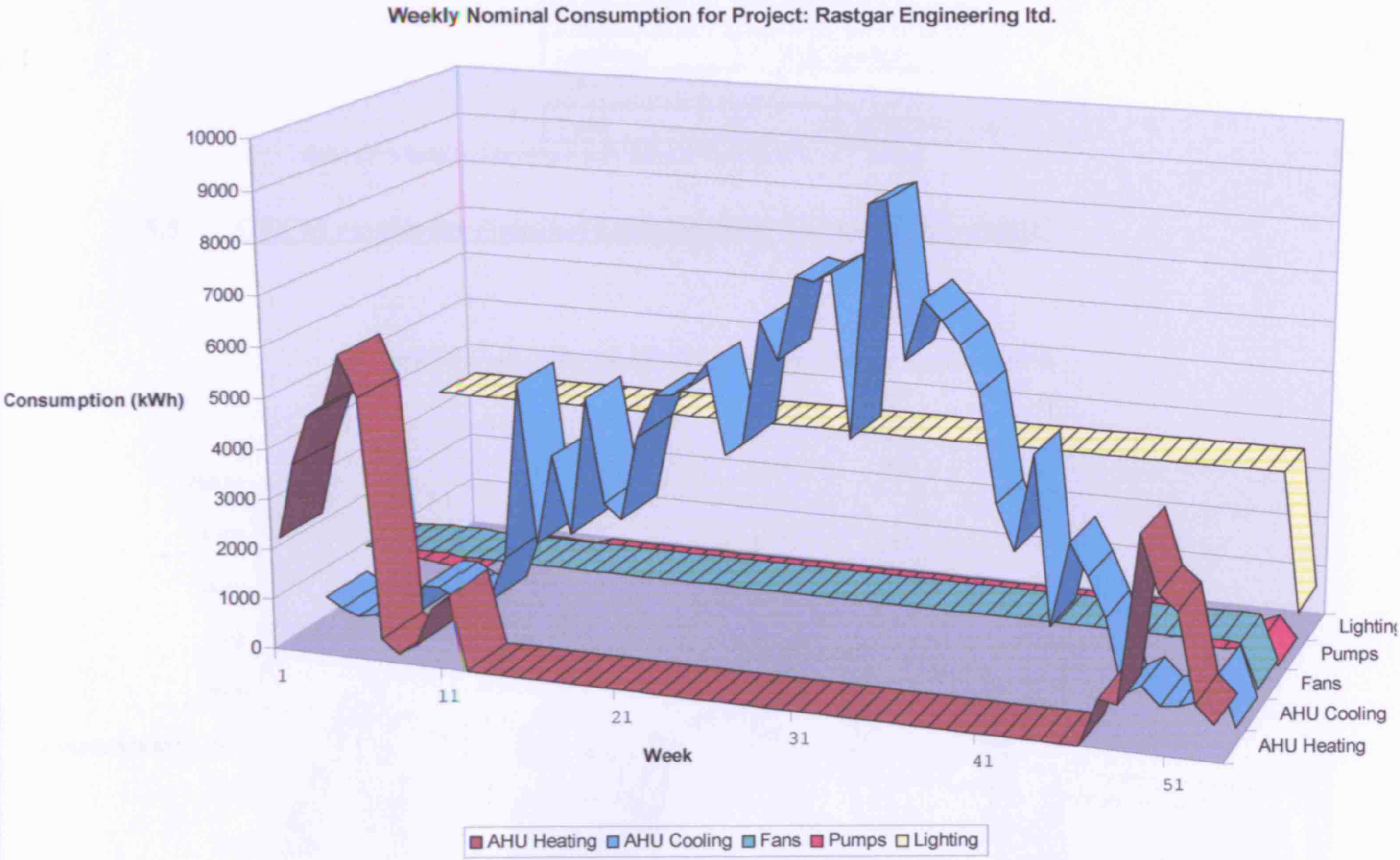


Figure 5.4: Weekly consumption of the nominal building for CAV system

	Central plant	Nominal building
Consumption	AHU Heating	17.30363892
	AHU Cooling	72.63222769
	Fans	21.53301488
	Pumps	10.11262036
	Lighting	69.47224864

Total	191.0537505	kWh/m^2

Table 5.7: Annual energy consumption for nominal building with 'CAV' systems

	Central plant	Designed building
Carbon Emissions	AHU Heating	0.917092863
	AHU Cooling	8.207441729
	Fans	2.433230681
	Pumps	1.142726101
	Lighting	7.850364096
	Total	20.55085547 kg/m^2

Table 5.8: Annual carbon emissions for nominal building with 'CAV' systems

5.5 CECM results for Nominal building with 'Variable air volume'

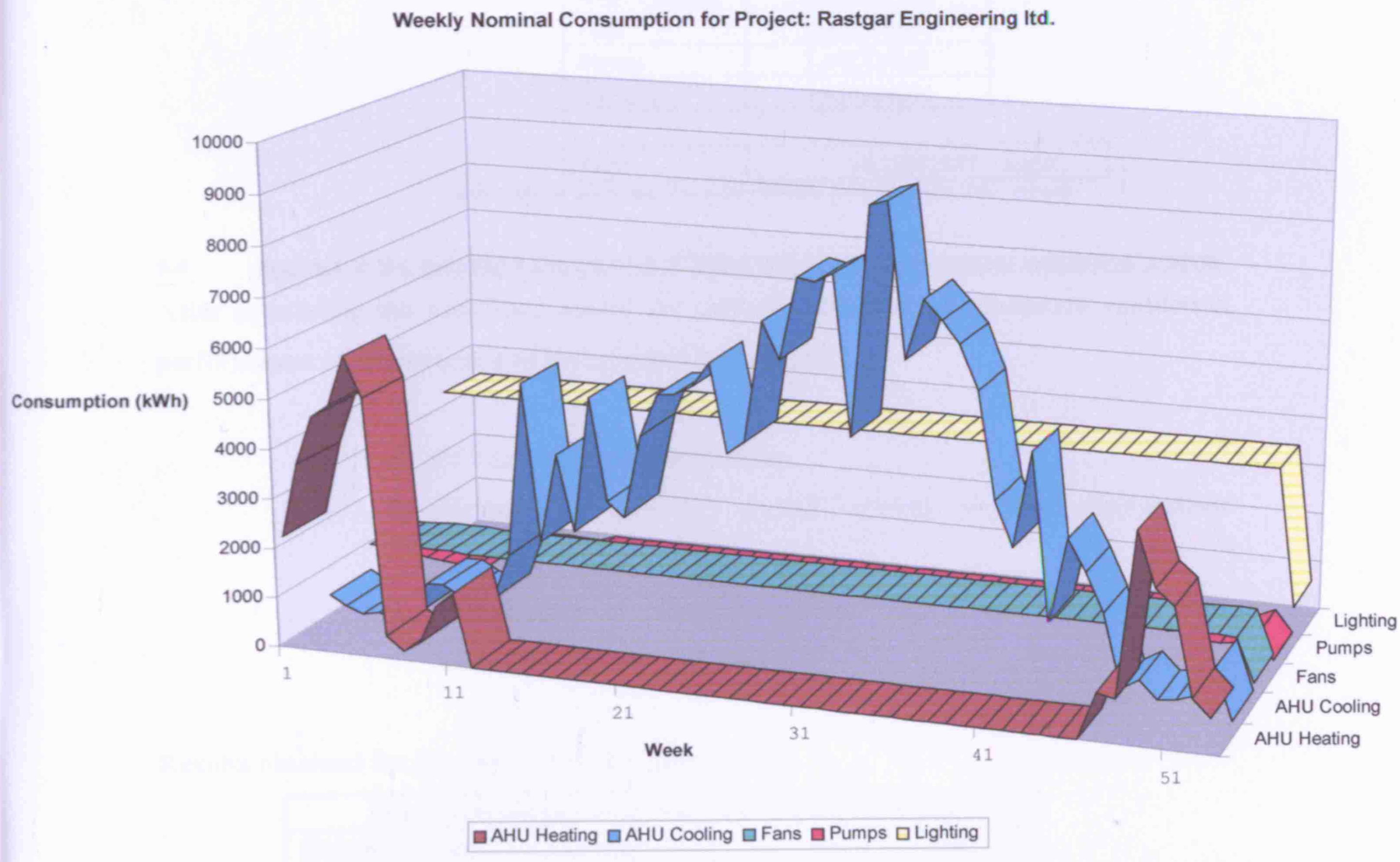


Figure 5.5: Weekly consumption of the nominal building for VAV system

Consumption	Central plant	Designed building
	AHU Heating	17.30363892
	AHU Cooling	72.63222769
	Fans	21.53301488
	Pumps	10.11262036
	Lighting	69.47224864
	Total	191.0537505 kWh/m^2

Table5.9: Annual energy consumption for nominal building with 'VAV' systems

Carbon Emissions	Central plant	Designed building
	AHU Heating	0.917092863
	AHU Cooling	8.207441729
	Fans	2.433230681
	Pumps	1.142726101
	Lighting	7.850364096
	Total	20.55085547 kg/m^2

Table 5.10: Annual carbon emissions for nominal building with 'VAV' systems

5.6 Analysis of the designed building with 'Chilled ceiling and displacement ventilation' system

After simulating the simplified model for chilled ceiling and displacement ventilation, performance of the system was investigated in three steps.

1. Performance without cooling.
2. Performance of the chilled ceiling without displacement ventilation.
3. Performance of the chilled ceiling with displacement ventilation with mass flow rate of 2.5 kg/s.

Results obtained for the first criteria are given below.

Maximum temperature obtained with out cooling		
External Temp. ^{o} C	Internal Temp.^{o} C	Surface Temp. ^{o}C
39.4	48.46754	41.0162

Table 5.11: Results without cooling

Results for the second criteria

Temperatures with chilled ceiling alone		
External Temp. °C	Internal Temp. °C	Surface temp. °C
41.7	36.5	18.9

Table 5.12: Results with chilled ceiling alone

Results for third criteria with a hot day

Temperature obtained for chilled ceiling with displacement ventilation				
External Temp. °C	Internal Temp. °C	Moisture content 'g/kg'	RH %	Surface temp. °C
41.7	24	7.6	40	19.1

Table 5.13: Chilled ceiling and displacement ventilation hot day

Results for third criteria with a hot and high relative humidity during office hours.

Temperature obtained for chilled ceiling with displacement ventilation				
External Temp. °C	Internal Temp. °C	Moisture content 'g/kg'	RH %	Surface temp. °C
36.9	22.9	10	57	18.4

Table 5.14: Chilled ceiling and displacement ventilation hot and humid

The third criteria were plotted on a psychometric chart to investigate the possibility of condensation occurring on the surface of the chilled ceiling. Results from psychometric chart for this criteria are as below.

Temperatures with chilled ceiling alone		
Internal Temp. °C	Moisture content 'g/kg'	Dew point. °C
22.9	10.2	14.5

Table 5.15: Results from psychometric chart

Dew point temperature for hot and hot/humid day		
Internal Temp. °C	Dew temp. for hot day '°C'	Dew temp. for hot and humid day °C
22.9	10	14.5

Table 5.16 : Dew point temperature for the chilled ceiling and displacement ventilation

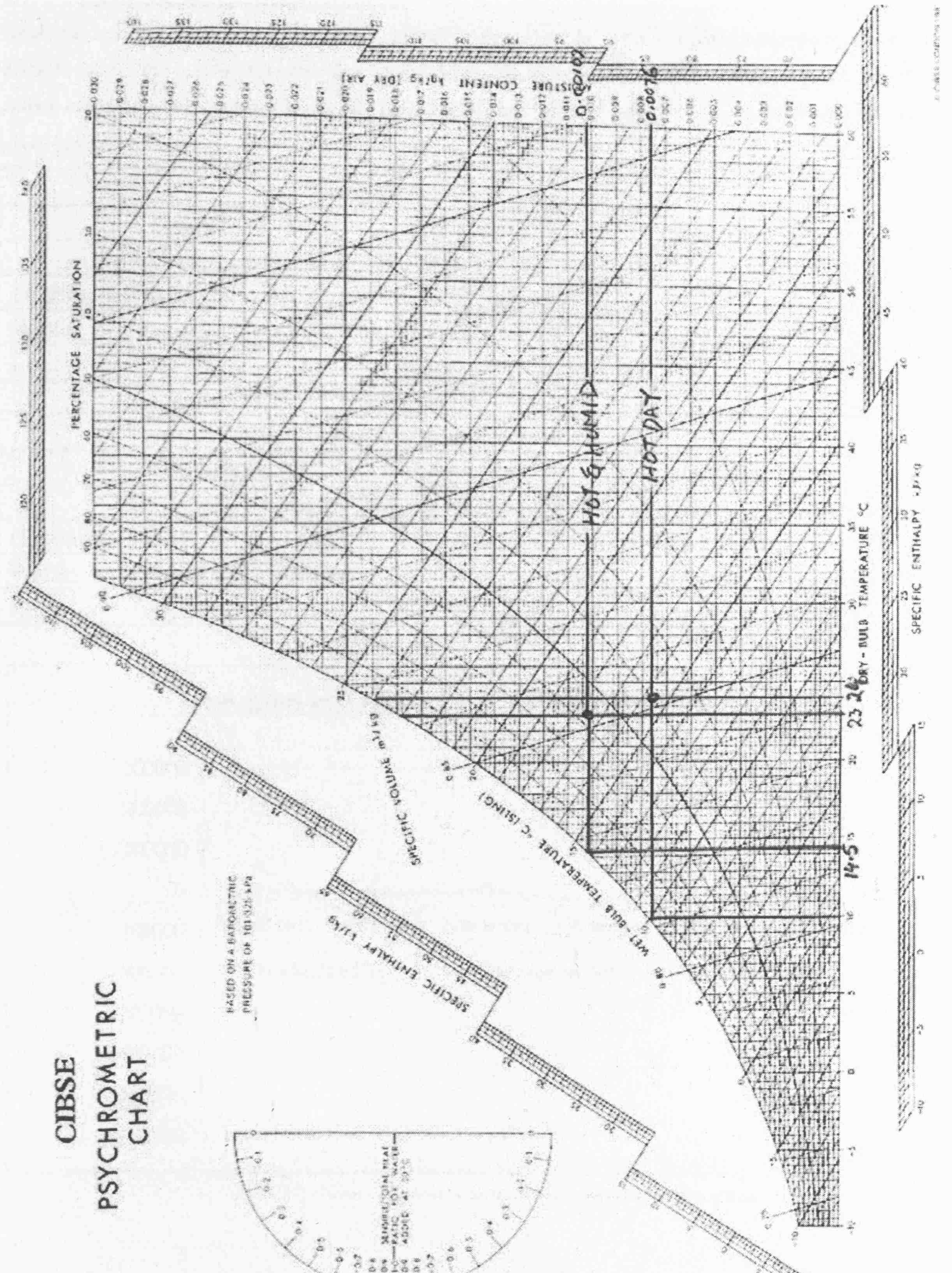


Figure 5.6: Psychometric chat for the chilled ceiling and displacement ventilation

5.7 Building fabric performance

Lastly the building fabric was analysed, this helped to determine the areas in which improvement could be made to reduce the buildings cooling and heating loads. By reducing these loads energy emissions and the carbon emission of the building could also be lowered. Heat loss and heat gain through building fabric are given below.

For typical winter week						
	Conduction 'W'		Convection 'W'		Radiation 'W'	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Glazing	13280.1	-4003.6	-180.8	-36613	-2170.3	-18744
Walls	66246.4	-88427	459.57	-68989	-8599.6	-67829
Roof	203300	-354102	-2109.1	-249975	-14927	-218200

Table 5.17: heat loss for typical winter week

For typical summer week						
	Conduction 'W'		Convection 'W'		Radiation 'W'	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Glazing	4511.19	-7312.1	1553.81	-19528	2.64428	-15915
Walls	56765.6	-73076	10575.3	-85662	-3766.7	-51693
Roof	252230	-467246	-2039.4	-445361	-54152	-429793

Table 5.18: heat gain for typical summer week

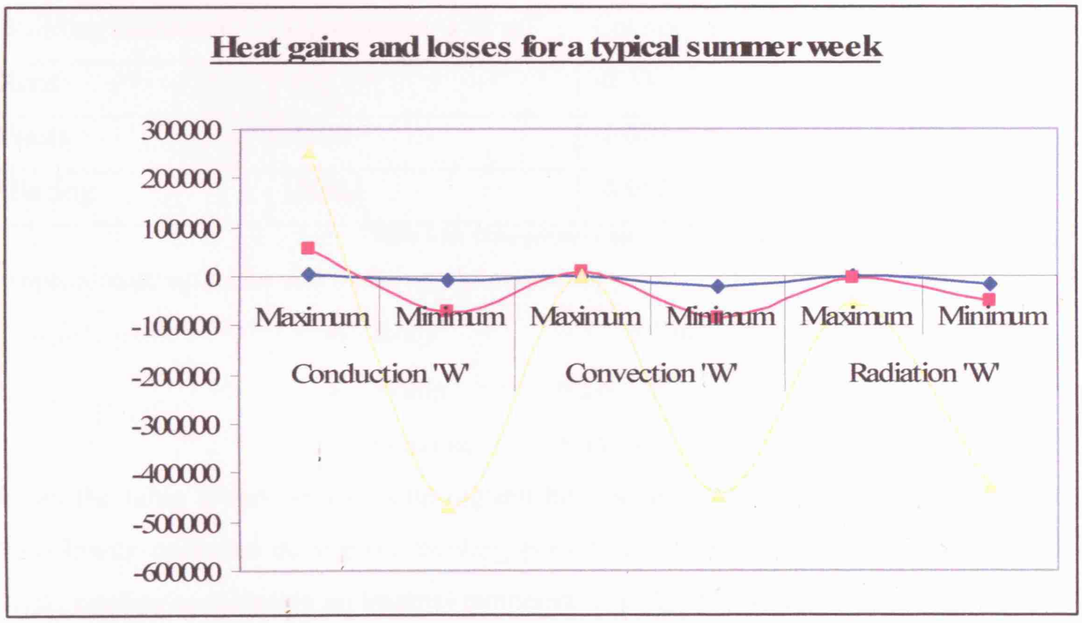


Figure 5.7: Graphical representation of heat loss and gains for summer week

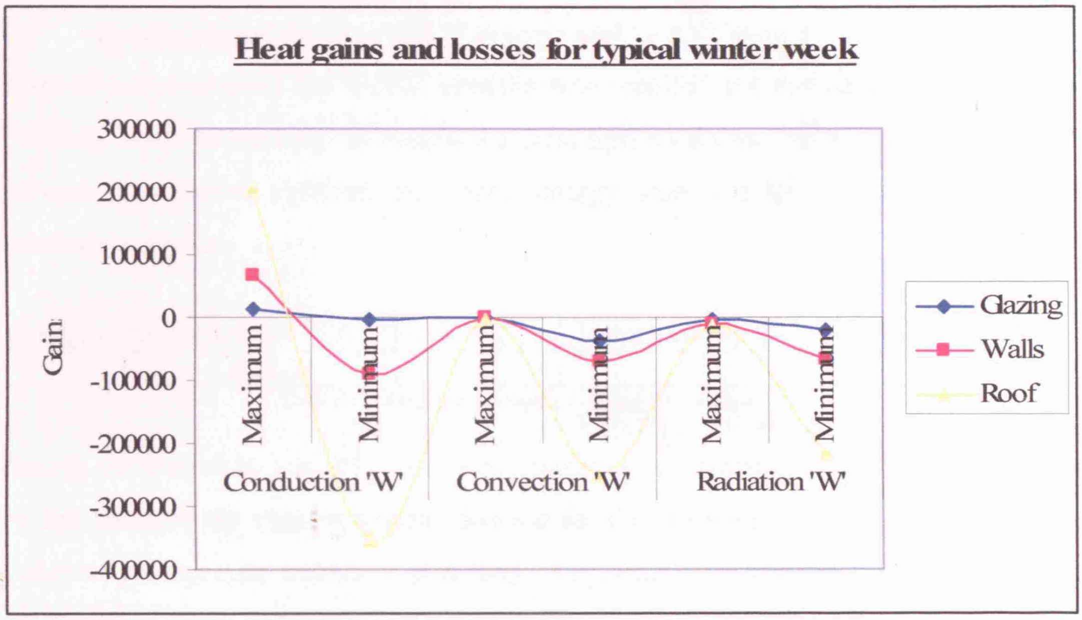


Figure 5.8: Graphical representation of heat loss and gains for winter week

From the tables given above heat losses per meter square for each building element can be calculated. These values are given in the table for summer week below.

Building elements	Conduction 'kW/m^2'	Convection 'kW/m^2'	Radiation 'kW/m^2'
Roof	-0.5	-0.33	-0.32
Walls	-0.02	-0.023	-0.014
Glazing	-0.001	-0.013	-0.011

Table 5.19: Gains per meter square of their area

Approximate areas for the building elements are;

- Roof = 1339.5 m^2
- Walls = 3640 m^2
- Glazing = 1404 m^2

From the table it can be seen that highest heat losses occurred through the roof. These heat losses occurred during the cooling period of the offices and are compensated by AHU cooling to maintain an internal temperature of 23 °C inside the building.

6.0 Comparison between 'CAV' system and 'VAV' system

Two different options for HVAC systems were applied and simulated for the designed building. After comparing the results for these options it was determined that constant air volume ventilation systems are more energy intensive than variable air volume ventilation system.

Energy consumption of 'CAV' in 'KWh'	Energy consumption of 'VAV' in 'KWh'
606.01	324.8

Table 6.1: Energy consumption of CAV and VAV systems

Energy consumed by variable air volume system was recorded at 46% less than that used by the constant air volume system. Reason for this difference is due to fact variable air volume systems runs mostly at part load. For variable air volume system full loads are only applied when occupancy load for the zone is present. On the other hand constant air volume systems run at their peak load irrespective of the occupancy schedule. For variable air volume when there is no occupancy schedule available, it reduces the mass flow of the air by 20% (standard practice for VAV system) which accounts for reduced energy consumption of the building. With the help of an adsorption chiller running on waste heat, energy consumptions given in the table 6.1 can be conserved provided there are enough heat sources available.

6.1 Chilled ceiling and displacement ventilation system

These systems are generally designed for low load environments. Chilled ceilings are effective to 60 W/m^2 environmental loads. The system load for the administrative floor of the designed building (where it was proposed to be installed and simulated) have gains of 100.3 W/m^2. Therefore when the building was given the option of chilled ceiling alone the temperature difference between the un-conditioned and conditioned space was 10°C and the internal temperature for the conditioned space was 35°C. In-order to maintain the internal temperature of 23°C displacement ventilation system was introduced. Whoever this temperature was maintained at the cost of high mass flow rate at temperature of 19°C.

Mass flow rate = 2.5 kg/s

Volume of the space = 285 m^3 (At which this mass flow rate is applied)

Air change rates induced by this mass flow rate are '31 ach'. This rate of ventilation is extremely high, therefore this form of ventilation system is not suitable for the building in hot climatic conditions with high environmental loads.

6.2 Optimal design

By looking into the building fabric and it's interaction with the HVAC system. The correlation between the two provides indications that the building fabric lacks in adequate environmental protection to the building. Highest heat gains and losses occurred through roof of the building by means of conduction to the external environment, followed by the external wall and the external glazing of the building. Reason for glazing working better than the other two building elements is that they are shaded from the sun by overhangs which also act as external walkways of the building.

From the results obtained by performing carbon emission calculation method, large differences in the energy consumption of the building with no insulation and same building with its elements according to Table 4 of Part L2 were noticed.

	Nominal building	Designed building	Difference %
Energy consumption	191.05	324.8	41.2

Table 6.2: Energy consumption for nominal and designed building with VAV system

The minimal optimal design for the building would be to provide insulated roof. This would cut down the fabric loss of 500 W/m^2 of the building through roof. This would also help in reducing the cooling design for the building.

6.3 Sizing of heat load for the chiller

The criteria to be followed in-order to size the chiller with the heat recovery system for the induction furnace are as follows.

- Amount of heat recovered from the heat source.
- Temperature at which the heat is recovered.
- Flow rate required to energize the chiller.

In 'Chapter 3', total usable heat that can be extracted from the induction furnace was determined and in 'Chapter 5' designed cooling load for the building were determined.

Available heat 'KW'	Designed cooling load 'KW'
418.73	465.96

Table 6.3: Designed and available heat for the sizing of chiller

It was initially proposed that chilling of cooling water would be provided by a single effect absorption chiller. For these machines co-efficient of performance ranges from 0.6 – 0.8. Considering COP of 0.8, than the required heat to energise the chiller would be.

Required heat load = 586 KW

At 80-90°C of hot water, whereas at present a heat source of 418.8 KW is available at 60°C. Therefore in-order to energise the chiller it would be required to increase the temperature of the water.

Since the heat source is not adequate to energise the single effect absorption chiller, alternate systems for cooling were looked at. An alternate to absorption chiller is an adsorption chiller (an example given in chapter 3) these machines are capable of running at a heat source of just 50°C with similar COP as absorption chiller.

At present, the heat source available is 28.5% less than the designed chiller capacity. An external source will be required to run the chiller for the designed cooling loads. Even though at present we have not been able to show that heat recovery from water cooling unit is a feasible proposal for this site. But with additional modification to following, adequate heat source can be made available. These modifications are;

1. Introducing insulation to the building fabric. This will reduce the cooling load of the building by 17.7 %.
2. Replace the existing cooling system for the induction furnace with a pressurised closed loop system. This will increase the amount of heat that can be extracted from the furnace, see chapter 3 section 3.7.3 for reference.
3. By looking into the possibility of running the cooling system of the furnace at higher delta T. According to 'Safe use of electric induction furnace' a study published by health and safety commission and electric council. Cooling circuit could be made to run for an inlet of 30°C and an outlet of 70°C safely, for pressurised close loop system. This would give us a delta T of 40°C at 70°C of hot water. At this setting we

would be able to generate enough heat so that an adsorption chiller could be used to provide the designed cooling loads for the building.

7.0 Conclusions

Aim of this case study was to find an appropriate HVAC system that could yield both;

1. Desired internal condition for the building.
2. Reduce the energy consumption resulting from HVAC system.

In doing so, we have looked into two different types of ventilation systems. A decrease of 46% in energy consumption was observed when constant air volume option was replaced by a variable air volume system. Further, 17.7% decrease in the cooling loads of the building was observed when insulation to the building elements was introduced. Considering these results, a minimum of roof insulation with variable air volume ventilation system is recommended. Even though, these option are more capital intensive than the standard practices of constant air volume ventilation and un-insulated building fabric. But the future benefits that would be achieved by the reduced running costs of the building would out weigh the initial capital costs for the building.

7.1 Future recommendation

1. Improve the air infiltration rate of the building. At present simulation were carried out for 0.7 ach.
2. Look into the possibility of adopting a mixed mode ventilation system for the building. This will decrease initial energy consumptions of the HVAC system for the start of the day. Since during night's most of the time the external dry bulb temperature in Islamabad are near 25°C.
3. Look into the feasibility of adopting pressurised close loop water cooling system for the induction furnace. This would help in utilising the waste heat from the cooling system of the furnace.
4. Introduction of building management systems, as they are known to reduce the energy consumption of the building by 30%.
5. Islamabad receives an average of 450 W/m^2 of global radiation, possibility of solar collection for the purposes of cooling should be looked at.

References:

1. The National energy conservation centre, Ministry of environment, LG&RD Government of Pakistan.
2. The 'Energy hand book 2000' publishes by the national energy conservation centre.
3. 'co-gen@cybernet.pk.'
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7. CIBSE guide Table 6.1, 6.7 and 6.11.
8. Foundries industry advisory committee 'safe use of electric induction furnace' by health and safety commission and electric council.
9. 'Absorption chiller' southern California gas company, new Building Institute, Advance design guideline series, November 1998.
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APPENDIX A

Table 6.1 Heat emission (W) from an adult male body (of surface area 2 m²) and average heat emission per person for a mixture of men, women and children typical of the stated application

Activity	Typical application	Occupancy density (m²/person)	Total, sensible and latent heat emission (W) for stated application and dry bulb temperature (C) for adult male (and average for mixture of men, women and children)										
			Total	15		20		22		24		26	
				Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent
Seated, inactive	Theatre, cinema matinee	0.75–1.0[2,3]	115 (100)	100 (87)	15 (13)	90 (78)	25 (22)	80 (70)	35 (30)	75 (65)	40 (35)	65 (57)	50 (43)
Seated, inactive	Theatre, cinema evening	0.75–1.0[2,3]	115 (105)	100 (91)	15 (14)	90 (82)	25 (23)	80 (73)	35 (32)	75 (68)	40 (37)	65 (59)	50 (46)
Seated, light work	Restaurant	1.0–2.0[2,3]	140 (126)	110 (99)	30 (27)	100 (90)	40 (36)	90 (81)	50 (45)	80 (72)	60 (54)	70 (63)	70 (63)
Seated, moderate work	Office	8–39[4-6], 14[4,7]*	140 (130)	110 (102)	30 (28)	100 (93)	40 (37)	90 (84)	50 (46)	80 (74)	60 (56)	70 (65)	70 (65)
Standing, light work, walking	Department store	1.7–4.3[2,3]	160 (141)	120 (106)	40 (35)	110 (97)	50 (44)	100 (88)	60 (53)	85 (75)	75 (66)	75 (66)	85 (75)
Standing, light work, walking	Bank	—	160 (142)	120 (107)	40 (35)	110 (98)	50 (44)	100 (89)	60 (53)	85 (76)	75 (66)	75 (66)	85 (76)
Light bench work	Factory	—	235 (209)	150 (133)	85 (76)	130 (116)	105 (93)	115 (102)	120 (107)	100 (89)	135 (121)	80 (71)	155 (138)
Medium bench work	Factory	—	265 (249)	160 (150)	105 (99)	140 (132)	125 (117)	125 (117)	140 (132)	105 (99)	160 (150)	90 (85)	175 (164)
Heavy work	Factory	—	440 (440)	220 (220)	220 (220)	190 (190)	250 (250)	165 (165)	275 (275)	135 (135)	305 (305)	105 (105)	335 (335)
Moderate dancing	Dance hall	0.5–1.0	265 (249)	160 (150)	105 (99)	140 (132)	125 (117)	125 (117)	140 (132)	105 (99)	160 (150)	90 (85)	175 (164)

* Recommended

Notes:

(1) Figures in parenthesis are adjusted heat gains based on normal percentage of men, women and children for the applications listed. This is based on the heat gain for women and children of 85% and 75% respectively of that of an adult male.

(2) For restaurant serving hot meals add 10 W sensible and 10 W latent for food per individual.

Table 1.1 Recommended comfort criteria for specific applications — *continued*

Building/room type	Winter dry resultant temperature range for stated activity and clothing levels*			Summer dry resultant temperature range† for stated activity and clothing levels*			Suggested air supply rate ($L{\cdot}s^{-1}{\cdot}person^{-1}$ except where stated otherwise)	Filtration grade‡	Maintained illuminance (lux)§	Noise rating (NR)¶
	Temp. (°C)	Activity (met)	Clothing (clo)	Temp. (°C)	Activity (met)	Clothing (clo)				
Hospitals and health care buildings: *(contd.)*										
— consulting/treatment rooms	22–24	1.4	0.55	23–25	1.4	0.45	8[2]	F7–F9	—[18]	30
— nurses' station[19]	19–22	1.4	0.9	21–23	1.4	0.65	8[2]	F7–F9	—[18]	35
— operating theatres	17–19	1.8	0.8	17–19	1.8	0.8	0.65–1.0 $m^3{\cdot}s^{-1}$	F9	—[18]	30–35
Hotels:										
— bathrooms	26–27	1.2	0.25	25–27	1.2	0.25	12[2]	F5–F7	150	40
— bedrooms	19–21	1.0	1.0	21–23	1.0	1.2	8[2]	F5–F7	50/100	20–30
Ice rinks	12	—	—	—	—	—	3 ACH	G3	200[20]	40–50
Laundries:										
— commercial	16–19	1.8	0.85	—[12]	—	—	—[21]	G3–G4	300/500	45
— launderettes	16–18	1.6	1.15	20–22	1.6	0.65	—[21]	G2–G3	300	45–50
Law courts	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F5–F7	300	25–30
Libraries:										
— lending/reference areas[22]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F5–F7	300	30–35
— reading rooms	22–23	1.1	1.0	24–25	1.1	0.65	8[2]	F5–F7	300[23]	30–35
— store rooms	15	—	—	—	—	—	—	F6–F8	200	—
Museums and art galleries:										
— display[24]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F7–F8	200[25]	30–35
— storage[24]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F7–F8	50[25]	30–35
Offices:										
— executive	21–23	1.2	0.85	22–24	1.2	0.7	8[2]	F7	500[7]	30
— general	21–23	1.2	0.85	22–24	1.2	0.7	8[2]	F6–F7	500[7]	35
— open-plan	21–23	1.2	0.85	22–24	1.2	0.7	8[2]	F6–F7	500[7]	35
Places of public assembly:										
— auditoria[26]	22–23[1]	1.0	1.0	24–25	1.1	0.65	8[2]	F5–F7	100–150[5]	20–30
— changing/dressing rooms	23–24	1.4	0.5	23–25	1.4	0.4	8[2]	F5–F7	100	35
— circulation spaces	13–20[1]	1.8	1.0	21–25[1]	1.8	0.65	8[2]	G4–G5	100	40
— foyers[27]	13–20[1]	1.8	1.0	21–25[1]	1.8	0.65	8[2]	F5–F7	200	40
— multi-purpose halls[28]	—	—	—	—	—	—	8[2]	G4–G5	300	—
Prison cells	19–21	1.0	1.7	21–23	1.0	1.2	8[2]	F5	100[4]	25–30
Railway/coach stations:										
— concourse (no seats)	12–19[1]	1.8	1.15	21–25[1]	1.8	0.65	8[2]	G4–G5	200	45
— ticket office	18–20	1.4	1.15	21–23	1.4	0.65	8[2]	G4–G5	500	40
— waiting room	21–22	1.1	1.15	24–25	1.1	0.65	8[2]	G4–G5	200	40
Restaurants/ dining rooms	22–24	1.1	0.9	24–25	1.1	0.65	8[2]	F5–F7	50–200[5]	35–40
Retailing:										
— shopping malls	19–24[1]	1.8	0.75	21–25[1]	1.8	0.65	8[2]	G4–G5	50–300	40–50
— small shops, department stores[22]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F5–F7	500/750	35–40
— supermarkets[29]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F5–F7	750/1000	40–45
Sports halls[30]:										
— changing rooms	22–24	1.4	0.55	24–25	1.4	0.35	6–10 ACH	G3	100[20]	35–45
— hall	13–16	3.0	0.4	14–16	3.0	0.35	8[2]	G3–F5	300[20]	40–50
Squash courts[30]	10–12	4.0	0.25	—	—	—	4 ACH	G3	300[20]	50
Swimming pools:										
— changing rooms	23–24	1.4	0.5	24–25	1.4	0.35	10 ACH	G3	100[20]	35–45
— pool halls	23–26	1.6	<0.1	23–26	1.6	<0.1	0–15 $L{\cdot}s^{-1}{\cdot}m^{-2}$ (of wet area)	G3	300[20]	40–50
Television studios[26]	19–21	1.4	1.0	21–23	1.4	0.65	8[2]	F5–F7	—[31]	25

Notes: Except where indicated[1], temperature ranges based on stated values of met and clo and a PMV of ±0.25. Upper temperature of stated range may be increased and lower temperature decreased by approximately 1°C if PMV of ±0.5 (i.e. 90 PPD) is acceptable (see section 1.3.3.2. Calculation assumes RH = 50% and v_r = 0.15 $m{\cdot}s^{-1}$. Insulation value of chair assumed to be 0.15 clo for all applications except dwellings, for which 0.3 has been assumed.

Elemental Method

1.7 To show compliance following the Elemental Method, the building envelope has to provide certain minimum levels of insulation, and the various building services systems each have to meet defined minimum standards of energy efficiency as follows -

Standard U-values for construction elements

1.8 The requirement will be met if the thermal performances of the construction elements are no worse than those listed in Table 1 (as illustrated in Diagram 1). One way of achieving the U-values in Table 1 is by providing insulation of a thickness estimated from the Tables in Appendix A as illustrated in the examples. An alternative for floors is to use the data given in Appendix C.

Table 1 Standard U-values of construction elements

Exposed Element	U-value (W/m²K)
Pitched roof [1,2] with insulation between rafters	0.20
Pitched roof [1] with insulation between joists	0.16
Flat roof [3] or roof with integral insulation	0.25
Walls, including basement walls	0.35
Floors, including ground floors and basement floors	0.25
Windows, roof windows and personnel doors (area weighted average for the whole building), glazing in metal frames [4]	2.2
Windows, roof windows and personnel doors (area weighted average for the whole building), glazing in wood or PVC frames [4]	2.0
Rooflights [5,6]	2.2
Vehicle access and similar large doors	0.7

Notes to Table 1:

[1] Any part of a roof having a pitch greater or equal to 70° can be considered as a wall.

[2] For the sloping parts of a room-in-the-roof constructed as a material alteration, a U-value of 0.3 W/m²K would be reasonable.

[3] Roof of pitch not exceeding 10°

[4] Display windows, shop entrance doors and similar glazing are not required to meet the standard given in this table.

[5] This standard applies only to the performance of the unit excluding any upstand. Reasonable provision would be to insulate any upstand, or otherwise isolate it from the internal environment.

[6] For the purposes of Approved Document L, a roof window may be considered as a rooflight.

Where an element is exposed to the outside via an unheated space (e.g. an unheated atrium or an underground car park), either:

a) The unheated space may be disregarded so that the element is considered as directly exposed to the outside, or

b) The U-value of the element may be calculated as the transmission heat loss coefficient through the unheated space divided by the area of the element. The transmission heat loss coefficient should be calculated as given in BS EN ISO 13789[28].

[28] 28 BS EN ISO 13789:1999 Thermal performance of buildings - Transmission heat loss coefficient - Calculation method

Table 4 Maximum allowable area of glazing

Orientation of opening	Maximum allowable area of opening (%)
N	50
NE/NW/S	40
E/SE/W/SW	32
Horizontal	12

Table 1 Standard U-values of construction elements

Exposed Element	U-value (W/m^2K)
Pitched roof [1,2] with insulation between rafters	0.20
Pitched roof [1] with insulation between joists	0.16
Flat roof [3] or roof with integral insulation	0.25
Walls, including basement walls	0.35
Floors, including ground floors and basement floors	0.25
Windows, roof windows and personnel doors (area weighted average for the whole building), glazing in metal frames[4]	2.2
Windows, roof windows and personnel doors (area weighted average for the whole building), glazing in wood or PVC frames[4]	2.0
Rooflights [5,6]	2.2
Vehicle access and similar large doors	0.7

<u>Part L2 table 1 & 4</u>

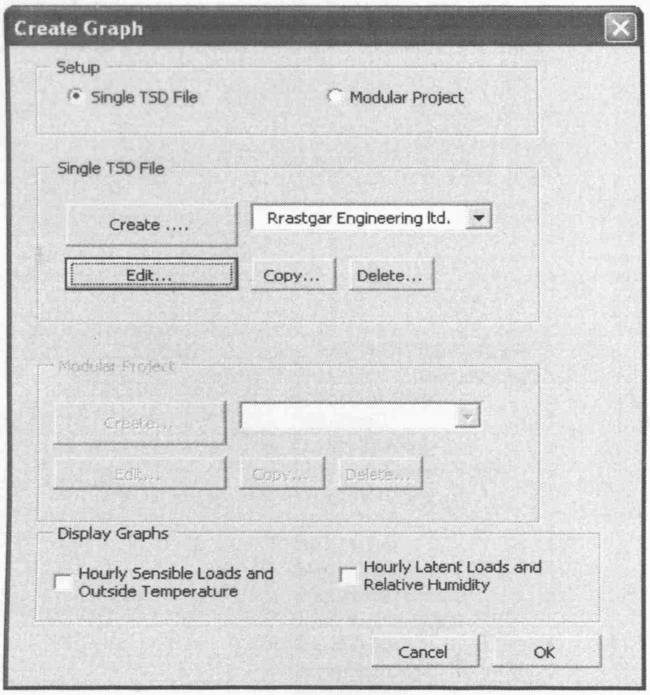
APPENDIX B

Setting up the Annual load macro

This macro can be setup by clicking on the 'Annual load' in the macro file of TAS, this macro opens up in Microsoft Excel program and can be run by clicking the 'Create graph' tab. Once the create graph tab opens there are two options available;

1. Single TSD file; used to generate graphs for single project.
2. Modular project, used if multiple TSD files or projects are accessed.

From this dialogue shown below, 'single TSD file' option was chosen.



In single TSD file option a subgroup named 'Rastgar Engineering ltd.' was created which contained information regarding the zones of the designed build that are to be looked in. Example given below;

After creating the sub-group file select 'ok' tab and than again select 'ok' tab in 'Create graph window in-order to generate annual, monthly weekly and daily graphs and tables for the designed building